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DESCRIPTION

METAL FOIL TUBE AND METHOD OF PRODUCTION AND PRODUCTION APPARATUS OF SAME

TECHNICAL FIELD

The present invention relates to a novel metal foil tube and a method of production and production apparatus for the same. More particular, it relates to a novel metal foil tube suitable for use for a copier, facsimile, etc. of an electronic photo printer, laser beam printer (LBP), toner roll, development roll, fixing roll, etc. and a method of production and production apparatus for the same.

BACKGROUND ART

In current electronic photo printers, laser beam printers (LBP), copiers, facsimiles, and other image forming devices, a photosensitive drum is exposed by an image signal, a developer forms a toner image, the toner image formed on this photosensitive drum is transferred to paper, and a fixer is used to fix it by heat for output. In such an image forming process, the photosensitive drum, toner roll, development roll, pressing roll, fixing roll, and various other roll members are used. Normally, these roll members are formed into tubular or cylindrical shapes and are designed to be driven by drive devices (motors etc.)

The tubular thin metal tube able to be used as a toner roll, development roll, fixing roll, etc. of such an electronic photo printer, laser beam printer (LBP), copier, facsimile, or other image forming device is required to exhibit the high elasticity, high rigidity, and high heat conductivity of the metal. Further, it is required to be made light in weight through ultra-thinning technology and to be smooth on the surface as a whole in order to achieve a high rotational precision free from vibration, uneven rotation, etc. having a

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detrimental effect on the desired sharp full color image quality and to be superior in durability. Therefore, such a thin metal tube is obtained by shaping and welding a stainless steel sheet etc. into a tubular shape by press working, laser welding, plasma welding, etc. to fabricate a tube blank (thick metal tube) and working this to an extremely thin thickness by ironing, spinning, drawing, bulging, or other thinning technology (for example, see Japanese Unexamined Patent Publication (Kokai) No. 2002-55557).

Further, as a method able to produce a thin metal tube able to be used as a toner roll, development roll, fixing roll, etc. of an electronic photo printer, laser beam printer (LBP), copier, facsimile, or other image forming device, the method of joining the end faces of a metal thin film sheet by a thermoplastic resin has been proposed (for example, see Japanese Unexamined Patent Publication (Kokai) No. 2000-280339).

However, with a thin metal tube obtained by working a tube blank (thick metal tube) fabricated by press working, laser welding, plasma welding, etc. by thinning technology, the structure of the weld zone melts once due to the laser welding or plasma welding, its hardness (Hv) falls to about half, and the strength also declines. Further, when thinning the tube blank, the surface becomes coarser compared with a metal rolled material (for example, stainless steel foil) (orange peel surface). For example, when spinning to work it by about 90%, there are the problems that the surface roughness (Rz) is about 3 μm and surface flaws occur along with the thinning. Therefore, there is the problem that a sufficient rotational precision is hard to obtain due to the vibration or uneven rotation having a detrimental effect on the desired sharp full color image. Further, in these thinning technologies, the process of production is complicated and the production cost tends to rise.

Further, with the method of joining the end faces of

a metal thin film sheet by a thermoplastic resin, the resin film covering the metal thin film has to be a thermoplastic resin. With a non-thermoplastic or heat curing polyimide or other resin, shaping is not possible. Further, compared with joining metal, when joining resin, the joint strength is weak and imparting long term durability is difficult. In particular, when used at a high temperature, heat embrittlement is seen in which the load applied to the joint zone causes separation at the joint zone etc. Therefore, this is not suitable for a toner roll etc. Further, the metal thin film has to be uniformly covered with another resin. There was therefore the problem of swelling production costs.

Therefore, an object of the present invention is to provide a novel thin metal tube having an extremely smooth surface, having the high elasticity, high rigidity, and high heat conductivity of the metal, extremely thin and light in weight, having a high rotational precision free from the vibration, uneven rotation, etc. having a detrimental effect on the desired sharp full color image, and excellent in durability without using press working, laser welding, plasma welding, thinning technology, or a resin material etc. and a method of production and production apparatus for the same.

To achieve the above object, the inventors engaged in intensive study of a novel thin metal tube and a method of production and production apparatus for the same and as a result discovered a method of production and production apparatus of a novel thin metal tube with almost no melted parts at all or a very small part and therefore free from a drop in hardness, high in durability, and enabling the weld zone to be finished smooth, through welding and/or crimping stainless steel foil or another metal foil substantially in a non-molten state without using the conventional press working, laser welding, plasma welding, thinning technology, or resin

material. Due to this, they discovered it is possible to remarkably lower the production costs and obtain a metal foil tube which, compared with the conventional thin metal tube obtained using thinning technology or a resin material, has the high elasticity, high rigidity, and high heat conductivity of the metal, is extremely thin and light in weight, is superior in surface smoothness, has a high rotational precision free from the vibration or uneven rotation etc. having a detrimental effect on the desired sharp full color image quality, and is excellent in durability and thereby completed the present invention.

Further, the inventors were not satisfied with the novel metal foil tube obtained by the novel method of production and production apparatus and engaged in intensive efforts to make further improvements. As a result, they obtained the following discoveries and made the further improvements of the present invention.

That is, in general, the weld zone becomes somewhat irregular in shape compared with the matrix of the metal foil and tends to become greater in surface roughness as well. The present invention welds and/or crimps the metal foil in the substantially non-molten state. Therefore, it is possible to finish the weld zone smooth, prevent the weld zone from becoming irregular in shape compared with the foil matrix, and further reduce the surface roughness. However, in the midsts of subsequent further research and improvements, the inventors learned that when welding and/or crimping metal foil in the substantially non-molten state, when using a soft foil material, the parts where the two sections are superposed can be easily crushed and further electrode flaws can be reduced, while on the other hand there are often cases where the material of the tube is desirably hard in order to increase the high-cycle fatigue life from the viewpoint of the performance in use. Therefore, as a means for dealing with this contradiction and further

improving the metal foil tube of the present invention, they discovered that by welding and/or crimping annealed foil in the substantially non-molten state and suitably thereafter cold working it by sedging, split roller rolling, drawing, spinning, or a combination of these methods so as to reduce the thickness, smooth the weld zone, even out the shape and surface roughness of the weld zone, and simultaneously work harden the material, it is possible to increase the fatigue life of the metal foil tube. Here, with SUS301, SUS304, or other metastable austenite steel, cold working causes a martensite phase to be formed. The work hardening is remarkable and hardening up to a Vicker's hardness of about 600 is possible. Further, while not to this extent, even with SUS304N1, SUS304N2, SUS316N, SUS836L, and other high nitrogen stainless steel or SUS201, SUS202, or other high Mn stainless steel, there is large work hardening and a Vicker's hardness of up to about 500 is possible. They learned that with other ordinary austenitic stainless steel, work hardening is possible up to about a Vicker's hardness of 430 and thereby further improved the present invention.

Further, in the present invention, the inventors discovered welding and/or crimping metal foil in the substantially non-molten state by joining by seam welding or mash seam welding or other electrical resistance welding, but later engaged in further research and improvements and during this discovered that a weld zone obtained by seam welding can be stably raised in the strength of the weld zone by the presence of continuous nuggets along the weld line (melted and solidified parts) or discontinuous nuggets along 50% or more of the weld line. That is, in seam welding for welding and/or crimping with substantially no melting, once nuggets are formed, even if the electrode wheel (see reference notation 32 in FIG. 6) proceeds to turn, most of the current flows to the nugget parts with the small

electrical resistance (invalid current). Since the interface to be newly joined has a large electrical resistance, only a small amount of current flow to it. Therefore, this part does not reach the welding temperature and is crimped. Once such a crimped part is formed, since this part also becomes small in electrical resistance, like with the nuggets, the formation of nuggets ahead of it is inhibited. To avoid this vicious cycle, the inventors used a pulse power source for seam welding, provided a short conduction time followed by a relatively long non-conduction time, and repeated this cycle and thereby succeeded in obtain continuous nuggets. The optimum ratio of the conduction time and non-conduction time at this time is 1/12 to 1/8. If less than 1/12 or over 1/8 to 1/6, discontinuous nuggets are formed. Experiments of the inventors revealed that even with discontinuous nuggets, if the weld line is covered 50% or more by the nuggets, there is no problem strengthwise. From the above, they learned that to obtain nuggets covering 50% or more of the weld length, it is necessary to use a pulse power source and set the ratio of the conduction time and non-conduction time to 1/15 to 1/7 for seam welding and thereby further improved the present invention.

On the other hand, even in mash seam welding able to weld and/or crimp in the non-molten state (due to the non-molten state, there are no melted parts, so there is the advantage that the hardness of the weld zone does not fall), to more stably improve the strength of the weld zone, it is possible to use a pulse power source for mash seam welding. At this time as well, the inventors discovered that there is an optimal ratio of the conduction time and non-conduction time. That is, they learned that with mash seam welding, it is preferable to use a pulse power source and set the ratio of the conduction time and non-conduction time to 1/3 to 1/1 for welding and thereby further improved the present

invention.

Further, the fixing roll of a printer sometimes becomes flawed at the surface due to the entry of foreign matter. Once flawed, this has a detrimental effect on the later printing results.

Further, in the novel metal foil tube discovered by the inventors, when seam welding the metal foil, quite often the nuggets formed by melting and solidification are not formed continuously. This part becomes relatively low in weld strength in the crimped state. It was learned that there is room for improvement. Therefore, it was learned that it was necessary to improve on these points to improve the yield and quality of the products.

Therefore, a further improvement of the present invention enables even these problems to be solved and provides, as a first aspect, a metal foil tube comprised of a metal foil joined and shaped by resistance welding etc. with at least one of its outside surface and inside surface hardened by a hard plating layer.

Further, it provides, as a second aspect, a metal foil tube where the plating layer is mainly comprised of one or two or more metals selected from chromium, nickel, cobalt, and palladium.

Further, it provides, as a third aspect, a metal foil tube where the plating layer is comprised of a Ni-P-based alloy.

Further, it provides, as a fourth aspect, a metal foil tube wherein the vicinity of the joint zone of at least one of the two surfaces of the stainless steel foil is plated with a Group X to XI element or an alloy containing at least one of these elements or a metal with a melting point of 1200°C or less and then the foil is resistance welded and a method of production of the same.

Further, it provides, as a fifth aspect, a metal foil tube where the plating layer is comprised of a Ni-P alloy containing by weight ratio 1 to 14% of P and a method of production of the same.

Further, it provides, as a sixth aspect, a metal foil tube comprised of a foil tube made of stainless steel foil joined by resistance welding etc. or further shaped and heat treated at a temperature of 800 to 1100°C and a method of production of the same.

Further, it provides, as a seventh aspect, a metal foil tube comprised of a foil tube made of stainless steel foil joined by resistance welding etc. or further shaped and heat treated at a temperature of 800 to 1100°C, then hard plated at least at one of the inside and outside surfaces of the foil tube and a method of production of the same.

The object of the present invention is achieved by the following means.

(1) A metal foil tube characterized by joining or welding a metal foil with a thickness of 10 to 100 μm.

(2) A metal foil tube as set forth in (1), characterized in that the metal foil is a stainless steel foil, and the stainless steel is one of ferritic stainless steel, martensitic stainless steel, austenitic stainless steel, and precipitation hardened stainless steel.

(3) A metal foil tube as set forth in (1) or (2), characterized by being joined by electrical resistance welding.

(4) A metal foil tube as set forth in (3), characterized in that the electrical resistance welding is seam welding.

(5) A metal foil tube as set forth in (4), characterized in that the seam welding is performed using a pulse power source and setting a ratio of the conduction time and non-conduction time to 1/15 to 1/7.

(6) A metal foil tube as set forth in (3), characterized in that the electrical resistance welding is mash seam welding.

(7) A metal foil tube as set forth in (6),

characterized in that the mash seam welding is performed using a pulse power source and setting a ratio of the conduction time and non-conduction time to 1/3 to 1/1.

(8) A metal foil tube as set forth in any one of (1) to (7), characterized in that at least part of the joint surface is a solid phase joint.

(9) A metal foil tube as set forth in any one of (1) to (8), characterized in that the joint or joint line is arranged in a line or spiral.

(10) A metal foil tube as set forth in any one of (1) to (9), characterized in that an absolute value of a hardness difference between the joint or weld zone and matrix part is, in terms of Vicker's hardness (Hv), 25% or less of the hardness of the matrix part.

(11) A metal foil tube as set forth in any one of (1) to (10), characterized by cold working the metal foil tube to reduce its thickness, smooth the joint zone or weld zone, even out the shape and surface roughness of the joint zone or weld zone, and work harden the material of at least the joint zone.

(12) A metal foil tube as set forth in any of (2) to (11), characterized in that the metal foil is a stainless steel foil, and the stainless steel foil is an annealed material of an austenitic stainless steel.

(13) A metal foil tube as set forth in any of (1) to (12), characterized in that the Vicker's hardness of the matrix part of the metal foil tube is 180 or less.

(14) A metal foil tube as set forth in any of (1) to (12), characterized in that the Vicker's hardness of the matrix part and weld zone of the metal foil tube is 300 to 600.

(15) A metal foil tube as set forth in any of (11) to (14), characterized in that a maximum nitrogen concentration of the surface layer of the stainless steel foil is 3 wt% or less.

(16) A metal foil tube as set forth in any of (2) to (15), characterized in that the stainless steel foil is a

soft austenitic stainless steel containing

C: 0.05 wt% or less,
Si: 0.05 to 3.6 wt%,
Mn: 0.05 to 1.0 wt%,
Cr: 15 to 26 wt%,
Ni: 5 to 25 wt%,
Mo: 2.5 wt% or less,
Cu: 2.5 wt% or less, and
N: 0.06 wt% or less,

and a balance of Fe and unavoidable impurities.

(17) A metal foil tube as set forth in any one of (2) to (11), characterized in that the stainless steel foil is a high strength austenitic stainless steel containing

C: 0.05 to 0.2 wt%,
Si: 0.05 to 3.6 wt%,
Mn: 1.0 to 5.0 wt%,
Cr: 15 to 26 wt%,
Ni: 5 to 25 wt%,
Mo: 5.0 wt% or less,
Cu: 4.0 wt% or less,
N: over to 0.06 wt% to 0.4 wt%,

and a balance of Fe and unavoidable impurities.

(18) A metal foil tube as set forth in any one of (2) to (12), characterized in that the metal foil is a stainless steel as rolled and the weld zone has a martensite phase precipitated at it.

(19) A metal foil tube as set forth in any one of (1) to (18), characterized in that a foil tube obtained by joining and shaping metal foil is surface hardened at least at one of its outside surface and inside surface by a hard plating layer.

(20) A welded metal foil tube as set forth in (19), characterized in that the hard plating layer is mainly comprised of one or more metals of chromium, nickel, cobalt, and palladium.

(21) A welded metal foil tube as set forth in (19),

characterized in that the hard plating layer is comprised of an Ni-P-based alloy.

(22) A welded metal foil tube as set forth in (21), characterized in that the hard plating layer is comprised of an Ni-P alloy containing, by weight ratio, 1 to 14% of P.

(23) A metal foil tube as set forth in any one of (1) to (22), characterized in that a vicinity of the joint zone of at least one of the two surfaces of the stainless steel foil is plated with a Group X to XI element or an alloy including such an element or a metal having a melting point of 1200°C or less and then the foil is resistance welded.

(24) A metal foil tube as set forth in any one of (1) to (18), characterized in that a metal foil tube obtained by joining or further shaping a stainless steel foil is heat treated at a temperature of 800 to 1100°C.

(25) A metal foil tube as set forth in any one of (1) to (18), characterized in that a metal foil tube obtained by joining or further shaping a stainless steel foil is heat treated at a temperature of 800 to 1100°C, then the foil tube is hard plated at least at one of the inside and outside surface.

(26) A metal foil tube as set forth in any one of (1) to (25), characterized in that a weld zone of the metal foil tube has continuous nuggets along the weld line or discontinuous nuggets present at least at 50% or more of the weld line.

(27) A metal foil tube as set forth in any one of (1) to (26), characterized in that an overlap (x) μm of the joint zone of the metal foil tube satisfies $x \leq 40+5t$ with respect to the metal foil thickness (t) μm.

(28) A metal foil tube as set forth in any one of (1) to (27), characterized in that the ratio of the inside diameter of the metal foil tube to the thickness of the tube is 1/500 or less.

(29) A metal foil tube as set forth in any one of (1) to (28), characterized in that a surface roughness Rz of the metal foil tube defined by JIS B0601-2001 is 2.0 μm or less.

(30) A metal foil tube as set forth in any one of (1) to (29), characterized in that the metal foil tube has a durability of 1 x 10^6 cycles or more in a fatigue test giving a strain of 0.2% or less at repeated cycles of 60 cycles/min or more.

(31) A metal foil tube as set forth in any one of (1) to (30), characterized in that it is used for a toner roll and/or development roll of an image forming device.

(32) A method of production of a metal foil tube characterized by comprising a shaping step of shaping a metal foil sheet with a thickness of 10 to 100 μm so that its facing sides overlap and a welding step of welding the overlapped facing sides.

(33) A method of production of a metal foil tube as set forth in (32), characterized by further having a finishing step of finishing the welded part smooth.

(34) A method of production of a metal foil tube as set forth in (32) or (33), characterized in that the shaping step has a positioning step of positioning the metal foil sheet at a shaping use core rod before overlapping the facing sides of the metal foil sheet.

(35) A method of production of a metal foil tube as set forth in (34), characterized in that the positioning step holds the metal foil sheet at a shaping device approaching and moving away from the core rod while constantly maintaining a parallel position with it, bringing the shaping device close to the core rod, and, when the metal foil sheet and core rod come into line contact, pressing and positioning the metal foil sheet with respect to the core rod.

(36) A method of production of a metal foil tube as set forth in (34) or (35), characterized in that the shaping step has, after the positioning step, a wrapping

step of bringing the shaping device closer to the core rod, holding the metal foil sheet between a semicircular cross-sectional recess formed at the shaping device and the core rod, and wrapping the metal foil sheet around the core rod.

(37) A method of production of a metal foil tube as set forth in (36), characterized in that after the wrapping step, the shaping step has an overlap adjusting step of adjusting the overlap by making part of the circumference of the metal foil sheet displace in the radial direction.

(38) A method of production of a metal foil tube as set forth in (36) or (37), characterized in that an overlap (x) μm satisfies $x \leq 40+5t$ with respect to the thickness (t) μm.

(39) A method of production of a metal foil tube as set forth in (32) or (33), characterized in that the welding step is electrical resistance welding.

(40) A method of production of a metal foil tube as set forth in (39), characterized in that the electrical resistance welding is seam welding or mash seam welding.

(41) A method of production of a metal foil tube as set forth in (40), characterized in that the electrical resistance welding uses a pulse power source and sets the ratio of the conduction time and non-conduction time to 1/15 to 1/7 for seam welding or uses a pulse power source and sets the ratio of the conduction time and non-conduction time to 1/3 to 1/1 for mash seam welding.

(42) A method of production of a metal foil tube as set forth in any one of (32), (33), or (39) to (41), characterized in that the welding step is performed by running a current between a conductive stationary electrode member provided in a groove formed along the axial direction of the outside surface of the core rod and a conductive movable electrode member provided facing the stationary electrode member.

(43) A method of production of a metal foil tube as

set forth in (42), characterized in that the stationary electrode member is formed so that part or all of the outside surface is flat.

(44) A method of production of a metal foil tube as set forth in (42) or (43), characterized in that the stationary electrode member and/or movable electrode member is comprised at least partially of molybdenum or alumina-dispersed copper alloy.

(45) A method of production of a metal foil tube as set forth in any one of (42) to (44), characterized in that the hardness of the stationary electrode member and/or movable electrode member and the hardness of the metal foil sheet are substantially the same.

(46) A method of production of a metal foil tube as set forth in any one of (34) to (36) and (42), characterized in that the metal foil tube is designed to be separated and removed from the core rod by ejecting a fluid from the inside of the core rod toward the radial direction.

(47) A method of production of a metal foil tube as set forth in any one of (34) to (37) and (42), characterized in that the core rod is comprised of a plurality of members and part is moved in the axial direction to separate the metal foil tube from the core rod.

(48) A method of production of a metal foil tube as set forth in any one of (32) to (47), characterized in that a ratio of the inside diameter of the metal foil tube to the thickness of the metal foil sheet is 1/500 or less.

(49) A method of production of a metal foil tube as set forth in any one of (32) to (48), characterized by inserting a metal core into the metal foil tube and cold working the tube by sedging, split roller rolling, drawing, spinning, or a combination of these methods to reduce the thickness, smooth the joint zone or weld zone to even out the shape and surface roughness of the joint

zone or weld zone, and work harden the material of the joint zone or weld zone.

(50) A method of production of a metal foil tube as set forth in any one of (32) to (49), characterized by plating the vicinity of the joint zone of at least one of the two surfaces of the stainless steel foil by a Group X to XI element or an alloy containing that element or a metal with a melting point of 1200°C or less and then resistance welding the foil.

(51) A method of production of a metal foil tube as set forth in any one of (32) to (50), characterized by heat treating a metal foil tube obtained by joining or further shaping a stainless steel foil at a temperature of 800 to 1100°C.

(52) A method of production of a metal foil tube as set forth in any one of (32) to (51), characterized by heat treating a metal foil tube obtained by joining or further shaping a stainless steel foil at a temperature of 800 to 1100°C, then hard plating at least one of the inside and outside surfaces of the metal foil tube.

(53) A method of production of a metal foil tube as set forth in (50) or (52), characterized in that the composition of the hard plating is an Ni-P alloy containing 1 to 14% of P by weight ratio.

(54) A method of production of a metal foil tube as set forth in any one of (32) to (53), characterized in that due to the welding of the metal foil tube, the weld zone has continuous nuggets along the weld line or discontinuous nuggets along 50% or more of the weld line.

(55) A production apparatus of a metal foil tube, characterized by having a shaping unit for shaping a 10 to 100 μm thick metal foil sheet to a predetermined shape and a welding unit for welding facing sides of the metal foil sheet.

(56) A production apparatus of a metal foil tube as set forth in (55), characterized in that the shaping unit

has a core rod of a circular cross-section perpendicular to the axis, a shaping device provided to be able to approach and move away from the core rod and holding the metal foil sheet, and a positioning member for making the shaping device approach the core rod and pressing against the metal foil sheet to position it with respect to the core rod at the time when the metal foil sheet and core rod come into line contact, and

making the shaping device move so as to make the positioned metal foil sheet approach the core rod and wrap the metal foil sheet in a U-shape around the core rod.

(57) A production apparatus of a metal foil tube as set forth in (56),characterized in that the shaping device has a holding plate provided so as to approach and move away from the core rod while constantly maintaining a parallel position with it and having a semicircular cross-section recess for wrapping the metal foil sheet in a U-shape with the core rod, a first pressing member for pressing one side of the U-shaped metal foil sheet so as to contact the circumference of the core rod, and a second pressing member for pressing the other side of the U-shaped metal foil sheet toward the circumference of the core rod, and

after the wrapping, overlapping the facing side edges of the metal foil sheet to form an overlap part.

(58) A production apparatus of a metal foil tube as set forth in (56) or (57),characterized in that the shaping unit has an overlap adjusting means for displacing part of the circumference of the metal foil sheet in the radial direction so that the overlap of the overlap part of the facing sides becomes a predetermined value before the end of the pressing action by the second pressing member.

(59) A production apparatus of a metal foil tube as set forth in (58),characterized in that the overlap adjusting means is comprised of offsetting devices

provided at the inside of the core rod.

(60) A production apparatus of a metal foil tube as set forth in (58), characterized in that the overlap adjusting means is comprised of offsetting devices provided at the outside of the core rod.

(61) A production apparatus of a metal foil tube as set forth in (58), characterized in that the overlap adjusting means is designed to press a non-contact part where the metal foil sheet does not contact the core rod by a pressing member.

(62) A production apparatus of a metal foil tube as set forth in (58), characterized in that the overlap adjusting means is designed to press a pressing member provided at the outside of the core rod into a recess formed in the core rod.

(63) A production apparatus of a metal foil tube as set forth in (61) or (62), characterized in that the pressing member is any of a cam, roll, tube, or rod-shaped member and is provided to operate separately at each of the two ends in the axial direction of the core rod.

(64) A production apparatus of a metal foil tube as set forth in (57) or (58), characterized in that the overlap (x) μm satisfies $x \leq 40+5t$ with respect to the thickness (t) μm.

(65) A production apparatus of a metal foil tube as set forth in (55), characterized in that the welding is an electrical resistance welding.

(66) A production apparatus of a metal foil tube as set forth in (55), characterized in that the welding unit is comprised of a conductive stationary electrode member provided along the axial direction of the outside surface of the core rod and a movable electrode member provided facing the stationary electrode member, grips the overlap part of the metal foil sheet between the two electrode members, and welds it in that state.

(67) A production apparatus of a metal foil tube as

set forth in (66),characterized in that the stationary electrode member is formed so that part or all of its outside surface is flat.

(68) A production apparatus of a metal foil tube as set forth in (66),characterized in that the movable electrode member is an electrode ring pressing against the overlap part and carrying a current.

(69) A production apparatus of a metal foil tube as set forth in any of (66) to (68),characterized in that the stationary electrode member and/or movable electrode member is comprised at least partially of molybdenum or an alumina-dispersed copper alloy.

(70) A production apparatus of a metal foil tube as set forth in any of (66) to (68), characterized in that a hardness of the stationary electrode member and/or movable electrode member and a hardness of the metal foil sheet are substantially the same.

(71) A production apparatus of a metal foil tube as set forth in any of (56),(57),or (66), characterized in that the metal foil tube is designed to be separated and removed from the core rod by ejecting a fluid from the inside of the core rod toward the radial direction.

(72) A production apparatus of a metal foil tube as set forth in any of (56),(57),or (66), characterized in that the core rod has a fluid passage for ejecting a fluid for separating the welded metal foil tube from the core rod.

(73) A production apparatus of a metal foil tube as set forth in any of (56),(57),or (66), characterized in that the core rod has grooves at its outer circumference for preventing the metal foil sheet from closely contacting the core rod.

(74) A production apparatus of a metal foil tube as set forth in any of (56),(57),or (66), characterized in that the core rod is comprised of a plurality of members and part is made to move in the axial direction so as to separate the metal foil tube from the core rod.

(75) A production apparatus of a metal foil tube as set forth in any of (55) to (74), characterized in that a ratio of an inside diameter of the metal foil tube to a thickness of the metal foil sheet is designed to be 1/500 or less.

(76) A metal foil tube characterized by being obtained using a method of production of the metal foil tube as set forth in (32) to (54) or a production apparatus of a metal foil tube as set forth in (55) to (75).

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1(A) is a plan view of a metal foil sheet for forming a metal foil tube.

FIG. 1(B) is a sectional view of a metal foil tube before welding.

FIG. 1(C) is a perspective view of a metal foil tube with a straight joint zone.

FIG. 1(D) is a perspective view of a metal foil tube with a spiral joint zone.

FIG. 2 is a schematic side view of a metal foil tube production apparatus according to an embodiment of the present invention.

FIG. 3 is a plan view of FIG. 2.

FIG. 4 is a sectional view along the line 4-4 of FIG. 3.

FIG. 5 is an enlarged sectional view of principal parts of FIG. 4.

FIG. 6 is an enlarged sectional view showing a state of welding of a metal foil tube production apparatus of an embodiment of the present invention.

FIG. 7 is a schematic sectional view along the axis of the core rod of a metal foil tube production apparatus of an embodiment of the present invention.

FIG. 8 is a schematic view of another example of a core rod of a metal foil tube production apparatus of an embodiment of the present invention.

BEST MODE FOR WORKING THE INVENTION

Below, embodiments of the present invention will be explained with reference to the attached drawings.

Metal Foil Tube

The present invention is a metal foil tube characterized by joining or welding metal foil of a thickness of 10 to 100 μm, preferably 20 to 50 μm. The metal foil tube of the present invention, as explained below, has the high elasticity and high rigidity characteristic of a metal, is thin, light in weight, and excellent in durability, has a high heat conductivity, and can be used for a toner roll, development roll, etc. of an electronic photo printer, laser beam printer (LBP), copier, facsimile, or other image forming device where a high rotational precision free of the vibration or uneven rotation having a detrimental effect on the desired sharp full color image quality is desired. In the conventional thinning technology, the surface inevitably ends up rough and smoothing is difficult. Only a surface with a surface roughness Rz of 3 μm or less could be obtained. With the metal foil as in the present invention, however, for example, when joining or welding a rolled stainless steel foil, the surface is smooth and a tube with a surface roughness of 2 μm or less can be provided. As a result, it is possible to provide a metal foil tube having a high rotational precision free from the vibration or uneven rotation having a detrimental effect on the desired sharp full color image quality. Further, with the conventional method of joining by a thermoplastic resin, a sufficient joint strength cannot be obtained and the durability becomes inferior, but with the present invention, since metal is joined, the joint strength is sufficient and the durability is superior. Further, with the conventional method of joining by a thermoplastic resin, it is necessary to coat thermoplastic resin to a uniform thickness on the surface of the metal foil and therefore the cost becomes high, but in the present invention, this

step is not required, productivity is excellent, and low cost metal foil tubes can be provided. Further, it is possible to provide a metal foil tube with a small power consumption, excellent in repeated mechanical stress, excellent in durability in a fatigue test etc., long in product life, free from heat embrittlement even in a temperature region of a high temperature of 200 to 400°C or so, suitable for use even for a toner roll etc., and enabling use of an alloy such as stainless steel. Further, it is possible to reduce the size and lighten the weight of the electronic photo printer, laser beam printer (LBP), copier, facsimile, or other image forming device and further save on energy.

Here, when the thickness of the metal foil tube of the present invention is over 100 μm, the heat conductivity becomes poor, so startup from the energy saving mode takes time. Further, the weight increases and the foil becomes thicker, so reduction of thickness and weight becomes difficult. Therefore, the demands from users and manufacturers for smaller size and lighter weight may not be able to be sufficiently met. On the other hand, the thinner the stainless steel foil, the better, but if less than 10 μm, the strength and rigidity are low and handling is difficult.

Note that, in the present invention, since the metal foil tube is comprised of the metal foil joined together as is, the surface roughness Rz can be made 2 μm or less, preferably 0.1 to 1 μm. This is because, as explained above, it is possible to obtain a metal foil tube by joining without detracting from the surface roughness of the rolled metal foil. Note that, in accordance with need, it is also possible to finish the surface after rolling. Further, if making the surface roughness Rz of the rolled metal foil less than 0.1 μm, the cost becomes high, so it is desirable to make the surface roughness Rz of the metal foil 0.1 μm or more. Due to this, as a metal

foil tube able to be used for the toner roll, development roll, etc. of an electronic photo printer, laser beam printer (LBP), copier, facsimile, or other image forming device, it is possible to provide a tube with excellent surface properties having a high elasticity and high rigidity, extremely thin, light in weight, excellent in durability, and having a high rotational precision free from vibration or uneven rotation having a detrimental effect on the desired sharp full color image quality.

Note that the surface roughness Rz may be measured by the measurement method defined in JIS B0601-2001 (maximum height roughness), but the invention is not limited to this.

Next, the metal foil material used for the metal foil tube of the present invention is not particularly limited. The optimal material may be suitably selected in accordance with the application. In the case of a fixing roll, development roll, heating roll, etc. of an electronic photo printer, laser beam printer (LBP), copier, facsimile, or other image forming device or other application, from the viewpoint of the ability to provide a tube having a high elasticity and high rigidity, extremely thin, light in weight, excellent in durability, and having a high rotational precision free from vibration or uneven rotation having a detrimental effect on the desired sharp full color image quality, a stainless steel foil is desirable. Specifically the material is any one of ferritic stainless steel, martensitic stainless steel, austenitic stainless steel, and precipitation hardened stainless steel. Note that, the precipitation hardened stainless steel, as shown in the later explained Example 7, is advantageous in the point of enabling electrical resistance welding or the like to be used for joining the foil to prepare a metal foil tube, polishing or otherwise finishing, then performing solid solution heat treatment along with the characteristics of stainless steel for example and, in

accordance with need, intermediate treatment, precipitation hardening heat treatment, etc. to cause precipitation hardening and obtain a high yield and further make the hardnesses of the matrix part and weld zone substantially the same and greatly improve the durability. The conditions for the solid solution heat treatment at this time and, if necessary, the intermediate treatment, precipitation hardening heat treatment, etc. may be optimally selected in accordance with the type of the stainless steel.

In the past, no technology had been established for directly joining metal foil, but the joining technology of the present invention enables use, in accordance with the purpose, for a broad range of materials from soft stainless steel foil to hard stainless steel foil. There is no limitation on the material used. It is possible to provide a metal foil tube able to be used for a broad range of applications. Note that the material of the metal foil tube of the present invention is not limited to these. For example, ultra-high purity Fe alloy, Ni and Ni alloy, Co and Co alloy, Ti and Ti alloy, Nb and Nb alloy, Zr and Zr alloy, Ta and Ta alloy, etc. may be used.

The material of the metal foil of the metal foil tube of the present invention is suitably a rolled material obtained by rolling a sheet of a stainless steel of any of ferritic stainless steel, martensitic stainless steel, austenitic stainless steel, or precipitation hardened stainless steel, an annealed material obtained by annealing this after rolling, or a tension annealed material etc., but the invention is not limited to these. Specifically, a rolled material obtained by rolling a sheet of any stainless steel of ferritic stainless steel foil of the JIS SUS400 series, SUSXM27, Tp.409, or other ferritic stainless steel foil, martensitic stainless steel foil of the JIS SUS400 series, austenitic stainless steel foil of the JIS SUS200 series and 300 series,

SUSXM7, SUSXM15J1, Tp.302B, Tp.314, and other austenitic stainless steel, or SUS630, SUS631, or other precipitation hardened stainless steel, an annealed material or precipitation hardened material obtained by annealing this after rolling, etc. may be mentioned.

Further, the metal foil tube of the present invention is preferably joined by electrical resistance welding. Specifically, the electrical resistance welding is seam welding, preferably mash seam welding. Further, the metal foil tube of the present invention is better in surface smoothness compared with the conventional thinning technologies, but to achieve this surface smoothness, it is necessary to join the joint zone and matrix part to be superior in surface smoothness as well and further make the hardness difference between the joint zone and matrix part 25% or less of the hardness of the matrix part in terms of Vicker's hardness (Hv). For this purpose, the joint is preferably joined by electrical resistance welding. Specifically, the electrical resistance welding is seam welding, preferably mash seam welding. In a metal foil tube using such a joining means, by employing a resistance welding method applying electrode pressure, that is, seam welding, and further a welding method welding while crushing the joint zone under the strong pressure of an electrode wheel to obtain a joint zone close to a butt joint, that is, mash seam welding, it is possible to continuously crush together the overlapping foil of the joint zone by a suitable electrode pressure to form a joint zone close to a butt joint. Therefore, the weld zone is flattened in thickness. At the time of the subsequent surface finishing, simple smoothing is sufficient without requiring an excessive load to be placed on the joint zone of the parts of the foil, therefore the production costs can be suppressed. As a result, it is possible to finish this to a smooth surface (joint zone) with a low surface roughness Rz.

Further, in the metal foil tube of the present invention, the weld zone of the metal foil tube preferably has continuous nuggets (melted and solidified parts) along the weld line or discontinuous nuggets along at least 50% of the weld line. This is because when joining by seam welding etc. enabling welding and/or crimping in the substantially non-molten state, the weld zone has continuous nuggets (melted and solidified parts) along the weld line or discontinuous nuggets along at least 50% of the weld line and therefore the strength of the weld zone can be kept stably high.

That is, in ordinary seam welding, once nuggets are formed, even when the electrode wheel (see reference numeral 32 of FIG. 6) proceeds to rotate, most of the current flows to the small electrical resistance nugget parts (invalid current). Since the interface to be newly joined has a large electrical resistance, only a small amount of current flows to it. Therefore, this part does not reach the welding temperature and is crimped in state. Once such a crimped part is formed, since this part also becomes small in electrical resistance, like with the nuggets, the formation of nuggets ahead of it is inhibited. To avoid this vicious cycle, the inventors used a pulse power source for seam welding, provided a short conduction time followed by a relatively long non-conduction time, and repeated this cycle and thereby succeeded in obtain continuous nuggets. The optimum ratio of the conduction time and non-conduction time at this time is 1/12 to 1/8. If less than 1/12 or more than 1/8 to 1/6, discontinuous nuggets are formed. However, experiments of the inventors revealed that even with discontinuous nuggets, if the nuggets can cover 50% or more of the weld line, there is no problem strength-wise. To obtain nuggets covering 50% or more of the weld length, the ratio of the conduction time and non-conduction time has to be set to 1/15 to 1/7. From the above viewpoint, in the metal foil tube of the present

invention, using a pulse power source and setting the ratio of the conduction time and non-conduction time to 1/15 to 1/7 for seam welding can be said to be preferable.

Further, mash seam welding enables welding and/or crimping in a non-molten state. This mash seam welding has the advantage that it is non-melting, so no melted parts are formed and therefore the hardness does not fall. In this as well, to more stably raise the strength of the weld zone, the inventors discovered that it is preferable to use a pulse power source for mash seam welding. At this time as well, there is an optimal ratio of the conduction time and non-conduction time. That is, in the metal foil tube of the present invention, using a pulse power source and setting the ratio of the conduction time and non-conduction time to 1/3 to 1/1 for mash seam welding can also be said to be a preferable embodiment.

Further, the weld zone of the metal foil tube of the present invention is a solid phase joint with no molten phase remaining except at the parts of the nuggets formed along the joint surface. Therefore, compared with laser welding or plasma welding where the molten phase remains extending across the entire thickness of the weld zone, it is possible to suppress a drop in strength due to a change in composition at the joint zone (change in crystal structure). Further, since the joint zone and non-joint zone (matrix part) are substantially the same in hardness and other mechanical properties, there is little cracking or joint separation due to sudden metal fatigue due to concentration of stress at the interface or joint surface between the joint zone and matrix part, and the durability becomes excellent. Therefore, when using the metal foil tube for the toner roll, development roll, etc. of an image forming device, it is possible to increase the service life. However, when the material used is a soft material, it is possible to reduce the

pressing force at the time of welding, leave the molten phase at the weld zone, and reduce the hardness difference from the matrix. From the above, it is preferable that at least part of the joint surface of the weld zone of the metal foil tube according to the present invention be a solid phase joint. In this case, the solid phase joint may be part or all of the joint surface. Note that if using mash seam welding enabling welding and/or crimping in the non-molten state, no nuggets are formed and the entire joint surface of the weld zone can be made a solid phase joint. This is preferable in that since no molten phase is formed, there is no drop in strength due to the change in composition of that joint zone (change in crystal structure).

By the electrical resistance welding (including seam welding and mash seam welding) or other welding in a substantially non-molten state and/or crimping, preferably the overlap (x) of the joint zone preferably satisfies $x \leq 40+5t$ with respect to the thickness (t) of the metal foil in the foil tube. Here, when the overlap (x) is larger than 40+5t, surface finishing should be performed. Note that here, the units of the overlap (x) and the thickness (t) of the metal foil are both µm.

In the metal foil tube of the present invention, it is preferable that the absolute value of the hardness difference (Vicker's hardness) of the weld zone and matrix part (non-weld zone) be 25% or less of the hardness of the matrix part in terms of Vicker's hardness (Hv). If the absolute value of the hardness difference of the weld zone and matrix part (non-weld zone) is over 25% of the hardness of the matrix part in terms of Vicker's hardness (Hv), at the interface between the weld zone and matrix part (non-weld zone), the metallurgical notch effect due to the hardness difference causes metal fatigue etc. and as a result susceptibility to cracks and fractures. Note that with the conventional laser welding method, the weld zone melts and the hardness remains

declined. The method of measurement of the Vicker's hardness (Hv) is based on JIS Z 2244 (1998). In the present invention, by suitably selecting the welding method, material, and heat treatment method, it is possible to suppress the hardness difference of the weld zone and matrix part (non-weld zone), possible to improve the durability of the metal foil tube as a whole, and possible to realize a high rotational precision with no uneven rotation or vibration due to its mechanical strength (hardness difference).

Further, in the metal foil tube of the present invention, as the stainless steel foil, ferritic stainless steel or martensitic stainless steel as rolled with a martensite phase precipitated at the weld zone preferably can be used. Specifically, SUS410L or another ferritic stainless steel, SUS403, SUS410, SUS420, SUS431, SUS440, or another martensitic stainless steel etc. may be mentioned as steels where the martensite phase precipitates at the weld zone. In the case of these steels, the weld zone is hardened by the precipitation of martensite due to the welding heat, the matrix part is hardened utilizing the work hardening due to rolling, and the hardness difference between the weld zone and matrix part is made smaller.

Further, with martensitic stainless steel, by heat treatment at a suitable temperature after welding, it is possible to adjust the hardness to a broad range of Hv300 to 600.

A metal foil tube using a hard material as the stainless steel foil may be suitably utilized for applications of a metal foil tube of for example, 30 μm or less thickness. In particular, when using a hard material as the stainless steel foil, the mechanical properties of the weld zone can be raised. Therefore, it is possible to extend the fatigue life and contribute to improvement of the durability. Further, it is possible to shorten the startup time from the energy saving mode.

Further, in the metal foil tube of the present invention, as the stainless steel foil, an annealed material obtained by rolling and annealing SUS304 or another JIS SUS 300 series austenitic stainless steel may be mentioned. The metal foil tube obtained by using a soft material as the stainless steel foil does not harden that much in the weld zone. Since the matrix part is a soft material, overall a soft tube can be obtained. In this case, by using an electrode material of a hardness substantially the same as the hardness of the metal foil, joining is possible without damaging either the electrode material and metal foil. In particular, when using an annealed material of austenitic stainless steel for the metal foil, this is advantageous also in the point of enabling combination of copper or another material excellent in electrical conductivity for the electrode material.

When using an annealed material of austenitic stainless steel as the metal foil, one with a Vicker's hardness (Hv) of the matrix part of 180 or less is preferable. This has the feature of excellent workability in the production stage and ease of shaping into a tube. Further, this is also superior in the point that even when precisely cutting out (punching) the metal foil, warping or strain of the edges etc. does not easily occur. Further, as an electrode material with a hardness substantially the same as the hardness of the metal foil, for example there are molybdenum, alumina-dispersed copper alloy, etc. Since these electrode materials can be used, damage to the electrode material or tube at the production stage can be suppressed.

In the above metal foil tube, from the viewpoint of excellent durability and wear resistance and longer high-cycle fatigue life, the Vicker's hardness (Hv) of the material, that is, the material of the matrix part and joint zone (weld zone) of the metal foil tube, is 300 to 600, preferably 400 to 500. That is, from the viewpoint

of excellent workability at the production stage and ease of shaping to a tube, the Vicker's hardness of the matrix part is preferably 180 or less. However, from the viewpoint of the performance in use, a hard tube material is preferable in many cases for increasing the high-cycle fatigue life. Therefore, it is also possible to cold work the metal foil tube obtained by joining or welding metal foil to reduce the thickness, smooth the joint zone, even out the shape and surface roughness of the joint zone, and work harden at least the material of the joint zone. Due to this, it is possible to raise the Vicker's hardness (Hv) of the material including the joint zone to a range defined above and possible to improve aspects of performance in use such as durability and wear resistance. As a result, it is possible to simultaneously achieve both workability at the welding stage and high high-cycle fatigue life from the aspect of performance in use.

In the present invention, it is also possible to work the entire metal foil tube including the weld zone to thin it, smooth the weld zone, even out the shape and surface roughness of the weld zone, and work harden the material of the entire tube including the weld zone. This is because, as explained above, in the case, as in the present invention, when welding and/or crimping metal foil in the substantially non-molten state, when using a soft foil material, the parts where the two sections are superposed can be easily crushed and further electrode flaws can be reduced, while on the other hand there are often cases where the material of the tube is desirably hard in order to increase the high-cycle fatigue life from the viewpoint of the performance in use. To eliminate this contradiction, in a further improvement of the present invention, it is possible to weld an annealed foil, then suitably thereafter cold work this by sedging, split roller rolling, drawing, spinning, or a combination of these methods to reduce the thickness, smooth the weld

zone, even out the shape and surface roughness of the weld zone, and simultaneously work harden the material. Due to this, it is possible to increase the fatigue life of the metal foil tube.

That is, as the metal foil tube suitable for the working method, one obtained by welding annealed foil in the above way is preferable, but the invention does not exclude one obtained by welding unannealed foil. That is, if it is possible to cold work a metal foil tube comprised of a metal foil joined or welded together to reduce the thickness, smooth the weld zone, even out the shape and surface roughness of the weld zone, and simultaneously work harden the material so as to increase the fatigue life of the metal foil tube, even welded unannealed foil is included in the technical scope of the present invention.

As the method for working the weld zone of the metal foil tube, for example, it is possible to cold work the weld zone by sedging, split roller rolling, drawing, spinning, or a combination of these methods. However, so long as it is possible to smooth the weld zone, even out the shape and surface roughness of the weld zone, and work harden the material of at least the weld zone, the invention is not limited to these cold working methods.

It is preferable to use the above working method for cold working to smooth the weld zone and even out the weld zone in appearance, shape, surface roughness, and hardness so as to be indistinguishable from the matrix part. Due to this, it is possible to provide a metal foil tube which can achieve a high rotational precision free from vibration or uneven rotation having a detrimental effect on the desired sharp full color image quality, has a smooth surface of the tube as a whole, and is excellent in durability.

Similarly, by smoothing the weld zone, the surface roughness is preferably leveled to a surface roughness Rz defined by JIS B0601-2001 (maximum height roughness) of

2.0 μm or less, preferably 0.1 to 1 μm. In particular, cold working by the working method is suitable for evening out the surface roughness and is extremely effective in terms of enabling adjustment to a value close to the lower limit of the preferable range (see later explained Table 1 of Example 9).

Further, it is preferable to cold work the metal fail tube and work harden the material and the material of the matrix part and joint zone (weld zone) of the metal foil tube to obtain a Vicker's hardness (Hv) of the material of 300 to 600, preferably 400 to 600, more preferably 450 to 550. Due to this, as explained above, it is possible to provide a welded metal foil tube suitable for use as a toner roll, development roll, etc. of an image forming device, excellent in durability and wear resistance, and having a hardness effective for increasing the high-cycle fatigue life.

Further, when using as the metal foil an annealed material of austenitic stainless steel, to prevent wrinkles, cracks, etc. when cutting out (punching) the metal foil at a high precision, the content of the nitrogen element in the stainless steel foil as a whole (bulk) is preferably 0.06 wt% or less, more preferably 0.03 wt% or less. Further, simultaneously, the maximum nitrogen concentration of the surface layer of the stainless steel foil is preferably 3 wt% or less. Here, the "surface layer of the stainless steel foil" means the oxide film formed on the surface due to the annealing. In general, the "oxide film" indicates the part of a depth from the surface-most layer down to where the oxygen concentration becomes 50% of the peak. If the content of nitrogen of the stainless steel foil exceeds 0.06 wt%, the stainless steel foil becomes hard, so easily fractures when the metal foil is cut out (punched) to a high precision and therefore is liable to easily crack. This is because with ordinary stainless steel sheet or just rolled stainless steel foil, the nitrogen content

does not remarkably increase, but if annealing this at the production stage, the N_2 gas in the atmosphere is taken into the stainless steel foil and remarkable nitridation occurs. Therefore, the nitrogen content of the bulk increases and simultaneously the nitrogen content in the oxide film at the surface layer remarkably increases. The nitrogen content of the surface layer increases relatively from that of the inside of the bulk, so the hardness becomes even higher than the inside of the bulk. As a result, when cutting out (punching) the metal foil with a high precision, shallow cracks occur in the surface layer and proceed in the thickness direction to lead to fractures.

Further, when using as the metal foil an annealed material of austenitic stainless steel, the material is specifically a sheet of stainless steel, in the SUS series, of SUS304, SUS304L, SUS304J1 (Cu added), SUS304J2 (17%Cr-7%Ni-4%Mn-2%Cu), SUS316 (Mo added), SUS316L (Mo added), SUS305, SUSXM7 (Cu added), SUS317, SUS317L, SUS309S, etc. and, in Nippon Steel Corporation's own steel of the YUS series, YUS304UL, YUS316UL (Mo added), YUS27A (Cu added), YUS110M (Cu, Si, and Mo added), YUS170, or other stainless steel, which is then rolled and annealed, but the invention is not limited to these. Sheets of SUS316, SUS304, or other stainless steel used most widely as stainless steel, already inexpensively and cheaply available as stainless steel sheet used for rolling, for which technology has been established for rolling to stainless steel foil, and suitable for annealing as well, which are then rolled and annealed are more preferable. In particular, sheets of SUS304J1 (17%Cr-7%Ni-2%Cu) and SUS304J2 (17%Cr-7%Ni-4%Mn-2%Cu) are large in effect of improvement of the shapeability and improvement of the age cracking due to the drop in C and N and addition of Cu. The press workability is highest among the steels illustrated above. Further, sheets of austenite stabilized steel such as SUS316 or SUS305 are

free from formation of work-induced martensite and the risk of age cracking. Note that the Ti added steel of SUS316Ti, SUS321, and the high Ni steels of SUS310S (25%Cr-20%Ni), SUS317J5L (21%Cr-24%Ni-4.5%Mo-1.5%Cu-low C), SUS384 (16%Cr-18%Ni), and SUSXM15J1 (18%Cr-13%Ni-4%Si) can also be used as the toner rolls, development rolls, etc. of electronic photo printers, laser beam printers (LBP), copiers, facsimiles, and other image forming devices.

Further, when using as the metal foil a soft austenitic stainless steel (soft material) or high strength austenitic stainless steel (hard material) such as an annealed material of austenitic stainless steel, the preferable ranges of the ingredients of the stainless steel are as follows:

C: C is an element stabilizing austenite, but when slightly high in content, the material becomes hard, so to obtain a soft material, the content is made 0.05 wt% or less, while to obtain a hard material, the content is made 0.05 to 0.2 wt%.

Si: Si has to be contained in an amount of 0.05 wt% for deoxidation. Further, it works effectively for oxidation resistance, but is a powerful ferrite forming element. If over 3.6 wt%, the workability is impaired, while simultaneously the descaling at the time of hot rolling becomes difficult, so the upper limit is made 3.6 wt%.

Mn: Mn is effective as an element stabilizing austenite and simultaneously fixes S to improve the hot workability. However, if the content is less than 0.05 wt%, the effect is small, while if over 1.0 wt%, the material becomes hard, so to obtain a soft material, the content is made 0.05 to 1.0 wt%, while to obtain a hard material, the content is made 1.0 to 5.0 wt.

Cr: Cr is a basic ingredient of stainless steel. To obtain excellent corrosion resistance, a minimum of 15 wt% is required. On the other hand, if over 26 wt%, the

steel becomes brittle and the workability deteriorates, so the upper limit is made 26 wt%. The preferable range is 17 to 19 wt%.

Ni: Ni is one of the basic ingredients of austenite stainless steel. It is an element effective for workability and corrosion resistance and is added in an amount of 5 wt% or more. However, even if added in an amount exceeding 25 wt%, these effects become saturated, so 5 to 25 wt% in range is preferable.

Mo: Mo is an element improving the corrosion resistance and is added in accordance with need. However, if the content is over 2.5 wt%, the steel hardens, while if over 5.0 wt%, the steel becomes brittle, so to obtain a soft material, the upper limit is made 2.5 wt%, while to obtain a hard material, the upper limit is made 5.0 wt%.

Cu: Cu is an element stabilizing austenite and improving the workability and corrosion resistance and is added in accordance with need. However, even if the content is added in an amount over 2.5 wt% with a soft material or over 4.0 wt% with a hard material, the effect becomes saturated, so to obtain a soft material, the upper limit is made 2.5 wt% and to obtain a hard material, the upper limit is made 4.0 wt%.

N: N is an element strongly stabilizing austenite and simultaneously improving the corrosion resistance and is added in an amount of at least 0.005 wt%. With a soft material, if contained in an amount over 0.06 wt%, the workability of the foil material after bright annealing (high precision cutting or punching and pressing) deteriorates and fractures or cracks easily occur. On the other hand, with a hard material, with a content of 0.06 wt% or less, a sufficient strength is difficult to obtain, while if contained over 0.4 wt%, the workability of the foil material (high precision cuttability or punch pressability) deteriorates and fractures or cracks easily occur. From the above, to obtain a soft material, the

content is 0.06 wt% or less, more preferably 0.007 to 0.03 wt% in range, while to obtain a hard material, the content is over 0.06 wt% to 0.4 wt%.

Further, the stainless steel may also contain fine amounts of additional elements of Ti, Ca, etc.

Further, the stainless steel may contain the above ingredients (including the above additional trace elements) in the above ranges (the amounts of the additional trace elements may be the suitable amounts in accordance with the purpose of use (normally Ti: 0.2 wt% or less, Ca: 0.0050 wt% or less), but the invention is not in particular limited to these) and a balance of Fe and unavoidable impurities. As unavoidable impurity elements, P, S, Al, O, etc. may be mentioned. The amounts of the unavoidable impurities are usually P: 0.045 wt% or less, Al: 0.05 wt% or less, S: 0.030 wt% or less, O: 0.01 wt% or less.

Further, in the metal foil tube of the present invention, at least one of the outside surface and inside surface of the foil tube joined by resistance welding of the metal foil and shaped is hardened by a hard plating layer. Below, a metal foil tube comprised of the foil tube of the present invention with an outside surface and inside surface hardened by a hard plating layer will be explained in detail.

The fixing roll of a printer sometimes is contaminated by foreign matter carried in along with the paper. Sometimes the roll becomes flawed as a result. This sometimes has a detrimental effect on the printing. Therefore, the surface hardness of the roll is preferably a Vicker's hardness of 400 or more. When not working the tube much after welding, this is achieved by hard plating the inside surface and outside surface of the metal foil tube. As the metal for plating, one mainly comprised of chromium, nickel, cobalt, palladium, or another metal is possible. To harden these, it is effective to add some P or other additive. In the case of plating by an Ni-P-

based alloy, a concentration of P of a weight ratio of 1 to 14% is preferable. The reason is that if less than 1%, the hardening effect is small, while if over 14%, the plating layer is brittle and cracks easily occur. The plating method may be electroless plating or electroplating, but to plate the inside (inner surface) of the foil tube, electroless plating is more convenient. The present invention is not limited in any way to the case of providing a hard plating layer on both the outside surface and inside surface of such a foil tube. It is also possible to provide just one with a hard plating layer. That is, when used for a toner roll, development roll, fixing roll, etc., it is effective to harden the surface (outside surface) of the foil tube contacting the photosensitive drum or other roll or paper etc. On the other hand, sometimes a heater is provided in the roll, so in this case, it is effective to harden the inside surface of the foil tube in advance. In this way, in accordance with the application of the metal foil tube, it is sufficient to provide a hard plating layer at the inside and/or outside surface of the foil tube.

Further, the metal foil tube of the present invention is obtained by heat treating a foil tube comprised of a stainless steel foil joined by resistance welding etc. or further shaped at a temperature of 800 to 1100°C.

When seam welding stainless steel, since the surface passive film of the stainless steel is strong, in order to completely break this and obtain a strong metal bond along the entire length of the weld line, welding within considerably narrow range of welding conditions obtained by detailed study on the current, voltage welding speed, conduction ratio etc. is required. In particular, in the case of mash seam welding for completely crushing two superposed layers of foil to reduce them to a thickness of a single layer, the current-carrying density to the part where the end faces of the foil are buried, that is,

the part where the crimping crushes the end faces of the superposed two sections of the foil to make them substantially integral, is low. Therefore, the bonding strength at this part is insufficient, and if repeatedly worked, sometimes the part will open up along the joint line. To solve this problem, the inventors discovered that two methods were effective.

One is to heat treat the foil tube comprised of stainless steel foil joined by resistance welding or further shaped so as to diffusion bond the joint line to increase the joint strength. In this case, the heat treatment may be vacuum heat treatment or heat treatment in an inert atmosphere. The heat treatment temperature is suitably 800 to 1100°C. When the stainless steel is ferritic or martensitic, a slightly lower temperature is also possible, while when it is austenitic, a slightly higher temperature is necessary. However, if less than 800°C, the diffusion bonding is insufficient. Further if over 1100°C, there is large deformation during heat treatment and the crystal grains also become coarser, so this is not preferable. Further, due to the heat treatment, there is the effect that the thermal stress around the weld zone is released and the stiffness often seen around the weld zone is eliminated. Further, if hard plating after the heat treatment, the small uneven parts of the weld zone are also concealed and the position of the weld zone can no longer even be discerned. Therefore, in the metal foil tube of the present invention, it is preferable to heat treat a foil tube comprised of stainless steel foil joined by resistance welding etc. or shaped at a temperature of 800 to 1100°C, then hard plate at least one of the inside and outside surfaces of the foil tube. The hard plating was explained above, so the explanation will be omitted here.

The second method is to plate the metal foil before welding in advance with Au, Ag, Cu, Ni, or another Group

X to XI element or an alloy containing the same (for example, an Ni-P-based alloy etc.) or Al or another metal with a melting point of 1200°C or less and resistance weld this to obtain a metal foil tube. With this method, even without the joint line part reaching the melting point of the stainless steel or other metal foil, so long as the temperature is higher than the melting point of the plating layer, the plating layer will melt and the majority will be pushed outside of the joint zone along the joint line along with the passive film at the surface of the stainless steel or other metal foil. Therefore, a complete metal bond is obtained along the weld line. Further, the part of the foil where the end faces are buried sometimes has small grooves, but this is also buried by the plated molten metal, so there is the advantage that no notches occur at the joint zone. Therefore, in the metal foil tube of the present invention, it is preferable to plate the vicinity of the joint zone of at least one surface of the metal foil with Au, Ag, Cu, Ni, or another Group X to XI element or alloy containing one or more of these elements (for example an Ni-P-based alloy etc.) or Al or other metal (including alloy) with a melting point lower than the melting point of the metal foil, preferably a metal (including alloy) with a melting point of 1200°C or less, then resistance weld the foil.

Further, in the metal foil tube of the present invention, the ratio of the inside diameter of the tube to the thickness of the tube (thickness/inside diameter ratio) is 1/300 or less, preferably 1/500 or less. Note that the thickness and the inside diameter of the tube spoken of here are in the allowable range, so the average of a plurality of locations (for example 5 to 10 locations or so) is used.

Further, the inside diameter of the metal foil tube is not particularly limited and may be suitably determined in accordance with the application, but for

example for a toner roll or development roll of an electronic photo printer, laser beam printer (LBP), copier, facsimile, or other image forming device, due to the strong demands for smaller size and lighter weight, a length able to match the currently used lengths of 50 mm or less is sufficient. In particular, in the later explained method of production and production apparatus of the present invention, it is possible to sufficiently meet this demand for smaller size. Even when the reduction of size results in a larger curvature of the tube and workability is required when shaping the tube, by using an annealed material of an austenitic stainless steel among the above stainless steel foils, it is possible to sufficiently handle small diameters of inside diameters of 10 to 15 mm.

Similarly, the length of the metal foil tube is not particularly limited and may be suitably determined in accordance with the application, but for example for a toner roll or development roll of an electronic photo printer, laser beam printer (LBP), copier, facsimile, or other image forming device, due to the strong demands for smaller size and lighter weight, a length able to match the currently used lengths of 500 mm or less is sufficient. In particular, in the later explained method of production and production apparatus of the present invention, it is possible to sufficiently meet this demand for smaller size. As the size becomes smaller, the contribution of the allowable error to the precision increases, but in the present invention, by using an annealed material of the austenitic stainless steel, strain does not easily arise when cutting out (punching) the foil to predetermined dimensions, so it is possible to obtain extremely high dimensional precision in punching and possible to sufficiently handle short tubes.

Further, the metal foil tube of the present invention preferably has a durability of 1×10^6 cycles or more, more preferably 2×10^6 cycles or more, in a fatigue

test giving 0.2% or less strain by a repeated cycle of 60 cycles/min or more. In the present invention, when utilized for a toner roll or development roll etc. for the following electronic photo printer, laser beam printer (LBP), copier, facsimile, or other image forming device, the fatigue test described above is generally used as the fatigue test. If the durability in this case is about 1 or 2 million cycles, it is possible to obtain an extremely high durability sufficiently higher than the durability of the current used parts. When the results of the fatigue test of the metal foil tube is less than 1 to 2 million cycles, it is not possible to strikingly improve the durability of the thin metal tube. Regarding the "durability" referred to here, when there are no cracks or fractures or other abnormalities in surface properties and further no joint separation or other abnormalities can be recognized in the joint zone, the state is deemed good and it is deemed that there is durability, while conversely when abnormalities are recognized, it is deemed that there is no durability. However, in the present invention, depending on the application, a result of the fatigue test of the metal foil tube of 500,000 cycles or more is sufficient for use.

Further, the applications of the metal foil tube of the present invention are not particularly limited, but for example it may be used for a toner roll or development roll etc. of an electronic photo printer, laser beam printer (LBP), copier, facsimile, or other image forming device, but the invention is not limited to these.

Metal Foil Tube Production Apparatus

Next, the production apparatus of the metal foil tube of the present embodiment will be explained. FIG. 1(A) is a plan view of a metal foil sheet for forming a metal foil tube, FIG. 1(B) is a sectional view of a metal foil tube before welding, FIG. 1(C) is a perspective view

of a metal foil tube obtained by welding so that the joint zone becomes straight, and FIG. 1(D) is a perspective view of a metal foil tube obtained by welding so that the joint zone becomes spiral. FIG. 2 is a schematic side view of a metal foil tube production apparatus according to an embodiment of the present invention, FIG. 3 is a plan view of FIG. 2, and FIG. 4 is a sectional view along line 4-4 of FIG. 3.

The metal foil sheet W used in the present embodiment, as shown in FIG. 1(A) and FIG. 1(B), is rectangular in overall shape, for example, has a length S_1 of 1 m and a width S_2 of 100 mm or so, while the thickness t is an extremely thin one of 10 to 100 μm. In the present embodiment, this metal foil sheet W is rounded to a circle in cross-section, the facing side ends are overlapped, and the overlap part G is welded to form a metal foil tube P. This metal foil tube P can be used, for example, for a fixing roll of a copier or other devices.

The metal foil tube production apparatus according to the present embodiment, roughly speaking, has a shaping unit 10 and welding unit 30. The shaping unit 10 does not round the rectangular metal foil sheet W all at once into a tube, but uses a shaping device 15 serving as an external die around the core rod 13 serving as an internal die to press it in stages and form it into a tube, while the welding unit 30 welds the overlapped part G of the facing side ends of the metal foil sheet W.

First, the shaping unit 10 will be explained. In FIGS. 2 and 3, the shaping unit 10 has a cylindrical core rod 13 supported in a cantilever fashion at a support part 12 projected on a base 11, a shaping device 15 positioned under the core rod 13, holding the metal foil sheet W, and wrapping it around the circumference of the core rod 13, and a positioning member 16 for positioning the metal foil sheet W with respect to the core rod 13.

The core rod 13 is somewhat longer than the length

direction length S_1 of the metal foil sheet W and has a thickness of about one turn of the length S_2 in the width direction of the metal foil sheet W. This core rod 13 will be explained in detail later.

The shaping device 15, as shown in FIG. 4, has a positioning member 16, holding plate 17, first pressing member 18, and second pressing member 19. The positioning member 16 is a member positioned at the approximate center of W and the center of the bottom surface of the core rod 13. The holding plate 17 is positioned below the core rod 13 and is connected with the cylinder C_1 provided on the base 11 so as to approach or move away from the core rod 13 while maintaining a parallel state with it at all times. This holding plate 17 has a flat top surface and is formed at its center with a semicircular cross-section recess 20 of an extent enabling the core rod 13 to be fit in it. The mating of this recess 20 and core rod 13 enables deformation of the metal foil sheet W and its being wrapped in a U-shape at the bottom part of the core rod 13.

The first pressing member 18 presses a side of U-shaped deformed metal foil sheet W rising up from the side faces of the core rod 13 against the circumference of the core rod 13 for close contact. This first pressing member 18, as shown in FIG. 4, is positioned at the left of the core rod 13 on the holding plate 17 and is designed to be moved by the cylinder C_2 to approach or move away from the rod in a direction perpendicular to the axis of the core rod 13.

The second pressing member 19 is also configured in the same way as the first pressing member 18, is provided at position symmetric with the first pressing member 18 across the core rod 13, is moved by the cylinder C_3 to approach and move away from the core rod 13, and presses the other side of the U-shaped metal foil sheet W toward the circumference of the core rod 13.

These positioning member 16, holding plate 17, first

pressing member 18, and second pressing member 19 operate together to wrap the metal foil sheet W around the circumference of the core rod 13 and form an overlap part G comprised of the superposed facing side ends of the metal foil sheet W, that is, the two ends in the width direction, on the top surface of the core rod 13.

Note that the metal foil sheet W is loaded onto the holding plate 17 of the shaping device 15 for example by a suitable conveyance means such as a vacuum suction means (not shown).

The positioning member 16 is a rod 21 passing through a through hole 21 formed in a semicircular cross-section recess 20 formed at the center of the shaping device 15 and is positioned below the core rod 13 at the base end, center, and front end in the axial direction. It is provided so as to approach and move way from the bottom surface of the core rod 13 by the cylinder C_4.

The positioning member 16 abuts against the bottom surface of the core rod 13 at the time of approach and presses against the metal foil sheet W so as to hold the metal foil sheet W at a fixed position. The timing when the positioning member 16 is actuated is the time when the metal foil sheet W placed on the top surface of the holding plate 17 is pushed up by upward movement of the holding plate 17 and comes into line contact with the core rod 13.

However, even if using the positioning member 16 for positioning, an overlap part G of a uniform width from the bottom end to front end of the core rod 13 is not necessarily formed. Therefore, in the shaping unit 10 of the present embodiment, an overlap adjusting means 22 for adjusting the overlap x of the overlap part G (see FIG. 1B) is provided (see FIG. 5). Here, FIG. 5 is an enlarged sectional view of principal parts of FIG. 4.

The overlap adjusting means 22 makes part of the circumference of the metal foil sheet W displace in the radial direction so that the overlap x of the overlap

part of the facing sides becomes a predetermined value, for example, about 0.1 mm, before the completion of the pressing action by the second pressing member 19.

Explaining this more specifically, the overlap adjusting means 22, as shown in FIG. 5, is provided inside the core rod 13 with offsetting devices (cams, rollers, etc.) 23 at least at the base end and front end of the core rod 13, drives the offsetting devices (cams, rollers, etc.) 23 by a drive device (motor etc.) M_1, and makes part of the circumference of the metal foil sheet W displace in the radial direction.

The amount of rotation of the offsetting devices (cams, rollers, etc.) 23 is controlled by a signal from the controller 24 so that the overlap x becomes a predetermined value. The controller 24 has a detection device for detecting the overlap x of the overlap part G (CCD camera etc.) 25 and a processor 26 for monitoring this, comparing it with the predetermined value, and determining the control amount.

Note that the drive device (motor etc.) M_1 may be provided at the base end of the core rod 13 and make a plurality of offsetting devices (cams, rollers, etc.) 23 provided at the base end, center, and front end operate all together, but it is also possible to make the offsetting devices (cams, rollers, etc.) 23 individually operate to adjust the overlap x.

However, the present invention is not limited to this. For example, as another overlap adjusting means 22, as shown by the dot-dash line in FIG. 5, it is also possible to provide the offsetting devices (cams, rollers, etc.) 23 at the outside of the core rod 13. Further, it is possible to provide them at the circumference of the core rod 13 so as to form non-contact parts where the metal foil sheet W does not closely contact the core rod 13 and press the sheet by a pressing member so as to make part of the circumference of the metal foil sheet W displace in the radial

direction.

Further, as schematically shown in FIG. 6, it is also possible to use a pressing member 28 provided at the outside of the core rod 13 facing the recess 27 formed in the core rod 13 to press the sheet so that part of the circumference of the metal foil sheet W displaces in the radial direction as shown by the broken line in the figure. The pressing member may be any of a cam, roll, cylinder, or rod member.

Experiments revealed that the overlap (x) preferably satisfies $x \leq 40+5t$ (unit μm) with respect to the thickness (t).

Next, the welding unit 30 will be explained. The welding in the present embodiment is a resistance welding method. Since an extremely thin metal foil sheet W is welded, an easily controllable welding method is necessary. In particular, among the resistance welding methods, seam welding is preferable, more preferably mash seam welding. If using this welding, the hardness difference between the weld zone and the other parts becomes small, whereby preferable results are obtained. Note that if using laser welding, plasma welding, etc., the hardness difference becomes 30% or more. It was learned that this was not practical.

FIG. 6 is an enlarged cross-sectional view showing the state of welding of the present embodiment. The welding unit 30, as shown in FIG. 6, is comprised of a conductive stationary electrode member 31 provided at the outside surface of the core rod 13 along the axial direction and a conductive movable electrode member 32 provided facing the stationary electrode member 31 and grips the overlap part G of the metal foil sheet W between the two electrode members for welding.

The stationary electrode member 31 is a conductive member provided in a groove 33 formed along the axial direction of the outer surface of a core rod 13. On the other hand, the movable electrode member 33 is a

conductive electrode ring 32 which rotates and moves while pressing against the overlap part G.

This stationary electrode member 31 is comprised of a copper material provided in a groove 33 provided in the top part of the core rod 13, but the electrode ring 32 performs welding while rotating on this, so the top surface of the stationary electrode member 31 is preferably formed flat overall. Therefore, as the stationary electrode member 31, for example, flat copper wire is used. However, there is no need for the top surface as a whole to be flat. Just part may also be flat. On the other hand, the electrode ring 32 preferably also has a flat circumference if the top surface of the stationary electrode member 31 is flat, but if the top surface of the stationary electrode member 31 is arc shaped, the circumference is preferably made recessed at the center, that is, hourglass shaped. The radius of curvature in this case is preferably larger than the radius of curvature of the arc-shaped surface of the stationary electrode member 31.

The electrode ring 32, as shown in FIG. 4, is connected through a conductive flanged-shaped rotational member 34 to the power supply member 35, but the power supply member 35 is supported by a non-conductive bracket 36. This bracket 36 is connected to be able to be elevated and lowered by the cylinder C_5. The cylinder C_5 is attached to a moving block 37, but this moving block 37 is supported slidably by a pair of guide rods 38 (see FIG. 3) and designed to move along the axis of the core rod 13 by a screw shaft 39 provided passing through the center. The screw shaft 39 is supported by bearings 42 provided on the support tables 40 and 41 and rotated by a drive device (motor etc.) M_2 connected through a coupling 43. That is, the electrode ring 32 is designed to be raised and lowered and moved by the cylinder C_5 and moved from the base end to the front end of the core rod 13 by the screw shaft 39 and drive device (motor etc.) M_2.

The hardness of the electrode members 31 and 32 is preferably made substantially the same as the hardness of the metal foil sheet W so as to prevent uneven contact or uneven wear and to enable reliable welding over a long period. The fact that if the Vicker's hardness HV is 180 or less, there is little electrode damage was found by experiments. To raise the high temperature strength or creep strength, the stationary electrode member 31 and movable electrode member 33 may be comprised at least in part by molybdenum or alumina-dispersed copper alloy.

In the present embodiment, since the overlap part G of the small overlap x of 0.1 mm of the extremely thin 10 to 100 μm metal foil sheet W is welded, the current value and feed rate become issues, but experiments showed that a current value of 700 to 1500 amperes or so, a voltage of 0.5 to 2.0V, and a feed rate of 0.3 to 1.5 m/min or so gave the best results.

However, if passing a current, the welding unit 30 is heated. If performing welding work over a long period of time, the heat causes the thin metal foil sheet W to deform and is liable to make good welding impossible. Further, since the metal foil sheet is wrapped around the circumference of a relatively long core rod 13 to form the metal foil tube P, separation and removal of this metal foil tube P also become an issue.

Here, in the present embodiment, as a means for solving all at once the problem of cooling (surface deformation) and the problem of removal, the core rod 13 itself is modified in various ways.

First, the core rod 13 functions as a die material for shaping the metal foil sheet W into a circular cross-section, so overall has a circular cross-section, but as shown in FIG. 6, the center part is provided with a core 13a comprised of ordinary mechanical structural use carbon steel having a Y-shaped cross-section. This core 13a has an electrode support 13b made of chromium steel superior in strength attached on it to hold the

stationary electrode member 31, while the side part of the core 13a is provided with a side plate 13c for finishing the entire part to a circular cross-section.

By doing this, even if the stationary electrode member 31 becomes worn, it is easily replaced. Shaping is also easy when shaping the whole into a circular cross-section.

Further, the core rod 13 is formed inside it, as shown in FIGS. 6 and 7, with a fluid passage 45. The fluid passage 40 is comprised of a center passage 45a formed in the center part along the axis of the core rod 13 and branch passages 45b formed in the radial direction from the center passage 40a. Note that FIG. 7 is a schematic sectional view along the axis of the core rod.

The fluid passage 45 is filled with air from a pipe 47 connected to one end of the core rod 13 through a rotary joint 46 (see FIG. 2). This air cools the core rod 13. Along with this, air is ejected from the branch passages 45b. Due to this, the metal foil tube P is lifted from the surface of the core rod 13 and made easy to detach.

If using air, there are the effects that the work efficiency is good and the work environment becomes clean, but the invention is not limited to this. Another fluid, for example, water, a cutting oil, etc. may also be used.

Further, to facilitate the detachment of the metal foil tube P from the core rod 13, the core rod 13 may be provided at its circumference with grooves R formed so as to extend in the axial direction (see FIG. 6). Due to this, the contact area between the metal foil sheet W and core rod 13 is reduced and the handling of the metal foil tube P becomes much easier.

Regarding the handling, the core rod 13 itself may also be comprised of a plurality of members which may be disassembled after formation of the metal foil tube P. FIG. 8 is a schematic sectional view showing another

example of a core rod. For example, as shown in FIG. 8, the core rod 13 is split at the taper surface 50 intersecting the axis into the two core rod members 13d and 13e. After shaping the metal foil tube, it is possible to slide one core rod member 13e in the axial direction with respect to the other core rod member 13d to separate the metal foil tube P from the core rod 13. However, when using this split core rod 13 for detachment, the core rod 13 is preferably supported at its two ends with one being designed to be able to move in the axial direction.

The metal foil tube obtained by the embodiment, as shown in FIG. 1(C), can give a metal foil tube having a joint zone with an overlap part G welded in a straight line. However, the present invention is not limited to these. For example, as shown in FIG. 1(D), it is possible to obtain a metal foil tube having a joint zone with an overlap part G' welded in a spiral. In this case, for example, a suitable thickness of metal foil is slit to a suitable width which is then wound around a copper alloy electrode rod in a spiral. At this time, the overlap x between the parts of the foil is adjusted by the detector to about 0.1 mm. Further, it is possible to rotate the electrode rod and make it slide to the left and right and roll over the overlap part by another copper alloy or other rolling electrode roller and pass current with the electrode rod for electrical resistance welding (preferably seam welding, more preferably mash seam welding). After this, it is possible to cut this tube to a suitable length and, in accordance with need, polish the inside and outside surfaces near the joint zone to obtain the desired metal foil tube.

Further, the ratio of the inside diameter of the metal foil tube with respect to the thickness of the metal foil sheet is 1/300 or less, preferably 1/500 or less. Note that the thickness of the metal foil sheet and inside diameter of the metal foil tube spoken of here are

in the allowable range of error, so the average value of a plurality of locations (for example, 5 to 10 locations or so) is used.

Note that when passing current to the electrode rod for seam welding, the weld zone can be stably increased in strength by the presence of the continuous nuggets (molten and solidified parts) along the weld line or the discontinuous nuggests along 50% or more of the weld line. That is, in seam welding, once nuggets are formed, even if the electrode wheel (see reference notation 32 in FIG. 6) proceeds to turn, most of the current flows to the nugget parts with the small electrical resistance (invalid current). Since the interface to be newly joined has a large electrical resistance, only a small amount of current flows to it. Therefore, this part does not reach the welding temperature and is crimped. Once such a crimped part is formed, since this part also becomes small in electrical resistance, like with the nuggets, the formation of nuggets ahead of it is inhibited. To avoid this vicious cycle, the inventors used a pulse power source for seam welding, provided a short conduction time followed by a relatively long non-conduction time, and repeated this cycle and thereby succeeded in obtain continuous nuggets. The optimum ratio of the conduction time and non-conduction time at this time is 1/12 to 1/8. If less than 1/12 or over 1/8 to 1/6, discontinuous nuggets are formed. Further, experiments of the inventors revealed that even with discontinuous nuggets, if the weld line is covered 50% or more by the nuggets, there is no problem strengthwise, so it is preferable to use a pulse power source and set the ratio of the conduction time and non-conduction time to 1/15 to 1/7 for seam welding. Due to this, it is possible to obtain nuggets covering 50% or more of the weld length.

Similarly, they discovered that even if using a pulse power source for mash seam welding, there is an

optimal ratio of the conduction time and non-conduction time for stably increasing the strength of the weld zone. That is, in mash seam welding, it is preferable to use a pulse power source and set the ratio of the conduction time and non-conduction time to 1/3 to 1/1 for welding.

Method of Production of Metal Foil Tube

The action of the apparatus for production of a metal foil tube configured in this way and the method of production of the metal foil tube will be explained next.

Shaping Step

A 10 to 100 μm thick metal foil sheet W is placed by a vacuum suction means or other conveying means on the holding plate 17 of the shaping device 15. The metal foil sheet W is held by a not shown guide member and set so that its center line matches the center axis of the core rod 13 and the center axis of the recess 20 formed in the holding plate 17.

From this state, the holding plate 17 starts to rise by the cylinder C_1, but the holding plate 17 holds a position parallel with the core rod 13 at all times. Therefore, when the metal foil sheet W contacts the core rod 13, the metal foil sheet W becomes substantially the same width centered about the core rod 13. When the metal foil sheet W contacts the core rod 13, the positioning member 16 operates.

The positioning member 16 is operated by the cylinder C_4, abuts against the center of the core rod 13 from the bottom, and grips the metal foil sheet W between the core rod 13 and the front end of the rod. This gripping action is performed by the base end, center, and front end of the core rod 13, so the metal foil sheet W contacts the core rod 13 along its entire length. Due to this, the metal foil sheet W is positioned at the substantial center in the width direction.

After this positioning, if the cylinder C_1 is further operated, the holding plate 17 rises and the core rod 13 starts to enter the recess 20 of the holding plate 17. As

a result, the metal foil sheet W is gradually deformed to a U-shape. Further, when the core rod 13 enters the recess 20, the metal foil sheet W is wrapped at the circumference of the bottom half of the core rod 13 and deformed to a pair of sides rising up from the sides.

The first pressing member 18 is made to project out toward one side by the operation of the cylinder C_3. This projection action is performed by the arc-shaped part 18a of the front end contacting the circumference of the core rod 13. This arc shaped part 18a presses one side of the metal foil sheet W against the circumference of the core rod 13 for contact.

Next, the second pressing member 19 is similarly operated by the cylinder C_3 and presses the other side of the metal foil sheet W until the arc-shaped part 19a of the front end contacts the circumference of the core rod 13, but this pressing action stops right before the final stage and therefore the metal foil sheet W is not completely in contact with the core rod 13.

That is, the metal foil sheet W is wrapped around the core rod 13 and the facing side ends of are superposed at the top of the core rod 13 to form an overlap part G. The other side is however not completely fixed in position and is made displaceable in state.

This displaceable state is used to adjust the overlap x of the overlap part G. This adjustment is performed by a detector (CCD camera etc.) 25 of the controller 24 detecting the amount of overlap x, the processor 26 comparing this with a predetermined value, judging whether it is normal, and, when not normal, driving the drive device (motor etc.) M_1 to make the offsetting devices (cams, rollers, etc.) 23 rotate and make the metal foil sheet W displace to the radial direction.

When the overlap (x) at the overlap part G satisfies $x \leq 40+5t$ (unit: μm) with respect to the thickness (t), the adjustment of the overlap x ends. In this state, the

second pressing member 19 operates by the cylinder C_3 and completely presses the other side of the metal foil sheet W into contact with the core rod 13. Due to this, the metal foil sheet W is held fixed in position on the core rod 13.

Welding Step

When the metal foil sheet W finishes being held, the overlap part G is positioned between the front end of the first pressing member 18 and the front end of the second pressing member 19 and directly above the stationary electrode member 31, and the electrode ring 32 can be raised and lowered between the first pressing member 18 and second pressing member 19, so welding can be started.

At the time of start of the welding, if positioning the electrode ring 32 at the base end of the core rod 13 and welding the entirety, good precision welding becomes possible.

The welding is first performed after actuation of the cylinder C_5. When the cylinder C_5 is actuated, the piston rod descends and the electrode ring 32 descends through the bracket 36, power supply member 35, and flange-like rotational member 34. The electrode ring 32 enters the space between the front end of the first pressing member 18 and the front end of the second pressing member 19 and grips the overlap part G with the stationary electrode member 31.

If running current through the stationary electrode member 31 and electrode ring 32 along with this gripping action, the overlap part G is welded together, simultaneously the drive device (motor etc.) M_2 also operates, the screw shaft 39 rotates, and the moving block 37 starts to move. Due to this, the electrode ring 32 moves over the overlap part G by 0.3 to 1.5 m/min or so and welds up to the end of the metal foil sheet W.

Further, in some cases, it is possible to position the electrode ring 32 at the front end of the core rod 13 and pull out the metal foil tube P while welding. If

doing this, fast, good work efficiency welding becomes possible.

Finishing Step

When the welding is completed, the welded part is finished smooth. This finishing is performed by polishing or lapping by a grindstone, crushing by roller burnishing, etc. until the surface of the metal foil tube P becomes a smooth surface, but known art is used, so explanations will be omitted.

Further, the metal foil tube P is detached from the core rod 13. This detachment action comprises supplying air from the end of the core rod 13 to the fluid passage 45 and ejecting air from the center passage 45a along the axis of the core rod 13 through the branch passages 45b toward the radial direction so as to separate the metal foil tube P from the core rod 13. If even a small amount of air flows between the core rod 13 and the metal foil tube P, the metal foil tube P can be easily detached from the core rod 13. Note that after detachment, the tube may also be finished.

In the above embodiment, the movable electrode member runs on the stationary electrode member or the metal foil tube P is made to move over it, but the present invention is not limited to this. The two electrode members may also be moved relative to each other or the two electrode members and the metal foil tube P may also be moved relative to each other.

The welded metal foil tube obtained by the above welding method may be used as is as the welded metal foil tube of the present invention for a broad range of applications, but, further, in accordance with need, it is also possible to insert a metal core into the welded metal foil tube obtained by the welding method and cold work it by sedging, split roller rolling, drawing, spinning, or a combination of these methods to reduce the thickness, smooth the weld zone to even out the shape and surface roughness of the weld zone, and work harden the

material.

The weld zone of the metal foil tube may be worked by the above-mentioned sedging, split roller rolling, drawing, spinning, or a combination of these methods. These sedging, split roller rolling, drawing, and spinning are known cold working technologies, so the explanations of these working methods will be omitted here.

The present invention covers the weld zone of a welded metal foil tube. Since handling is difficult in that state, it is possible to insert a metal core into the metal foil tube in advance to place it in a state enabling cold working (mainly plastic working) and to work it in that state.

As the metal core, it is preferable to use one made of a quenched material with a high hardness such as for example S45C and an outside diameter matching the inside diameter of the welded tube. When the working would change the inside diameter of the tube, it is preferable to change the metal cores to ones with outside diameters matching the same.

Further, with sedging, the metal core is inserted into the welded tube, then three or four tools arranged at the outside of the tube are used to strike the surface of the tube and reduce the tube thickness.

Further, with split roller rolling, the metal core is inserted into the welded tube, then a plurality of small diameter rollers arranged at the outside of the tube are pressed by separate fixtures or a backup roll and the tube and plurality of small diameter rollers are made to rotate relative to each other to reduce the thickness of the tube.

Further, drawing is a method of passing a somewhat thick material (here the welded foil tube with the metal core inserted in it) through a conical hole (die). If using a suitable lubricant, it is possible to reduce the thickness without changing the diameter of the tube.

Further, with spinning, the welded foil tube with the metal core inserted in it is rotated and one or more flat tools are pressed against the outside surface of the tube to reduce its thickness.

In these cold working, when the tube is brought close to the finished dimensions, it is possible to switch to sufficiently small work tools or rollers with sufficiently small surface roughnesses so as to shape the weld zone to an uneven thickness and smoothness. In the metal foil tube of the present invention, it is preferable to cold work it to thin it until a surface roughness Rz defined by JIS B0601-2001 (maximum height roughness) of 2.0 μm or less, preferably 0.1 to 1 μm and smoothly even out the weld zone.

Further, the tube is preferably cold worked to thin it and work harden the material so as to make the Vicker's hardness (Hv) of the material 300 to 600, preferably 400 to 600, more preferably 450 to 550. Due to this, as explained above, it is possible to provide a welded metal foil tube excellent in durability and wear resistance, increased in high-cycle fatigue life, and having effective hardness. Note that, the "Vicker's hardness" of the material referred to here includes the hardness of both the matrix part and weld zone of the metal foil tube.

Further, in the method of production of the metal foil tube of the present invention, when seam welding the stainless steel, since the surface passive film of the stainless steel is strong, in order to completely break this and obtain a strong metal bond along the entire length of the weld line, welding within considerably narrow range of welding conditions obtained by detailed study on the current, voltage welding speed, conduction ratio etc. is required. In particular, in the case of mash seam welding for completely crushing two superposed layers of foil to reduce them to a thickness of a single layer, the current-carrying density to the part where the

end faces of the foil are buried, that is, the part where the crimping crushes the end faces of the superposed two sections of the foil to make them substantially integral, is low. Therefore, the joint strength at this part is insufficient, and if repeatedly worked, sometimes the part will open up along the joint line. To solve this problem, the inventors discovered that two methods were effective. The first method is to heat treat the foil tube comprised of stainless steel foil joined by resistance welding etc. or further shaped for diffusion bonding and increasing the strength. In this case, the heat treatment is conducted by vacuum heat treatment or in an inert atmosphere. The heat treatment temperature is suitably 800 to 1100°C. When the stainless steel foil is ferritic or martensitic, a slightly lower temperature may be used, while when austenitic, a slightly high temperature is necessary. However, if less than 800°C, the diffusion bonding is insufficient, while if over 1100°C, there is large deformation during the heat treatment and the crystal grains become coarse, so this is not preferred. Further, due to the heat treatment, there is the effect that the thermal stress around the weld zone is released and the stiffness often seen around the weld zone is eliminated. Further, if hard plating after the heat treatment, the small uneven parts of the weld zone are also concealed and the position of the weld zone can no longer even be discerned. As the metal for hard plating, one mainly comprised of chromium, nickel, cobalt, palladium, or another metal may be used. To cause these to harden, it is effective to add slight amounts of P or other additives. In the case of plating by a Ni-P-based alloy, the concentration of P is preferably 1 to 14%. The reason is that if less than 1%, there is little effect of hardening, while if over 14%, the plating layer becomes brittle and easily cracks. As the plating method, electroless plating or electroplating is possible, but

electroless plating is convenient for plating the inside of the tube.

The second method is to plate the metal foil before welding in advance with Au, Ag, Cu, Ni, or another Group X to XI element or alloy containing such an element (for example, Ni-P-based alloys etc.) or Al or another metal (including alloy) with a melting point lower than the melting point of the metal foil, preferably a metal (including alloy) with a melting point of 1200°C or less, and to resistance weld this to obtain a metal foil tube. With this method, even without the joint line part reaching the melting point of the stainless steel or other metal foil, so long as the temperature is higher than the melting point of the plating layer, the plating layer will melt and the majority will be pushed outside of the joint zone along the joint line along with the passive film at the surface of the stainless steel or other metal foil. Therefore, a complete metal bond is obtained along the weld line. Further, the part of the foil where the end faces are buried sometimes has small grooves, but this is also buried by the plated molten metal, so there is the advantage that no notches occur at the joint zone.

Further, in the method of production of the metal foil tube of the present invention, due to the welding of the metal foil tube, the weld zone preferably has continuous nuggets (melted and solidified parts) along the weld line or discontinuous nuggets along 50% or more of the weld line. This is because if the seam welded or other weld zone has continuous nuggets (melted and solidified parts) along the weld line or discontinuous nuggets along 50% or more of the weld line, it is possible to stably raise the joint strength of the weld zone.

Further, in seam welding, once nuggets are produced, even if the electrode wheel (see reference notation 32 in FIG. 6) proceeds to turn, most of the current will flow

to the small electrical resistance nugget parts (invalid current). Since the interface to be newly joined has a large electrical resistance, only a small amount of current will flow to it. Therefore, this portion will not reach the welding temperature and will be crimped. Once such a crimped part is formed, since this part will also be small in electrical resistance, like nuggets, formation of nuggets ahead of it will be inhibited. To avoid this vicious cycle, the inventors used a pulse power source for seam welding, provided a short conduction time followed by a relatively long non-conduction time, and repeated this cycle to thereby succeed in obtaining continuous nuggets. The optimum ratio of the conduction time and non-conduction time at this time is 1/12 to 1/8. If less than 1/12 or over 1/8 to 1/6, discontinuous nuggets are produced. Experiment by the inventors revealed that even with discontinuous nugget, if covering the weld line over 50% or more by nuggets, there is no problem strengthwise. To obtain nuggets covering 50% or more of the weld length, the ratio of the conduction time and non-conduction time has to be set to 1/15 to 1/7. From the above, in the method of production of the metal foil tube of the present invention, it is preferable to use a pulse power source and set the ratio of the conduction time and non-conduction time to 1/15 to 1/7 for seam welding.

Further, the inventors discovered that even when using a pulse power source for mash seam welding, there is an optimal ratio of conduction time and non-conduction time for more stably raising the strength of the weld zone. That is, in the method of production of the metal foil tube of the present invention, it is preferable to use a pulse power source and to set the ratio of the conduction time and nonconduction time to 1/3 to 1/1 for the mash seam welding.

Examples

The effects of the present invention will be

explained using the following examples and comparative examples. However, the technical scope of the present invention is not limited to the following examples. Note that the units of dimensions not particularly indicated are "mm" units.

Example 1

Stainless steel foils made of SUS410L (11%Cr-0.02%C) were rolled to thicknesses of 40 μm while suitably controlling the rolled surface roughnesses to give surface roughnesses Rz of 1.5 μm and 0.8 μm. The rolled materials were cut to 94.3 mmL x 250 mmW. The foils having the two types of surface roughnesses were wrapped around 30 mmϕ copper alloy tools and joined at the 100 μm overlap parts by mash seam welding. At this time, the vicinities of the joint zones of both tubes ((a) tube having a surface roughness Rz of 1.5 μm and (b) tube having a surface roughness Rz of 0.8 μm) were cut out, buried, and polished. In both cases, it was confirmed that the hardness of the matrix part was, in Hv, around 270, while the hardness of the joint zone was, in Hv, around 230. The two polishing samples were etched and examined for metal structure. As a result, in both cases, there was no melted and solidified phase at the joint zone, the joint surface was a solid phase in state, and a low carbon martensite phase was seen here. Note that the thickness of the joint zone was 55 μm in both cases. The two tubes (see FIG. 1(C)) were cut to lengths of 50 mm, the inside and outside surfaces near the joint zones were polished, and the thicknesses of the two joint zones were made 42 μm or so. In both cases, a hard sponge tube was inserted. This was rotated while pressed against the surface of a 120 mmϕ x 80 mmL steel roller to investigate the fatigue life. The rotational speed of the tested tube at this time was 120 rpm. In the state most pressed against the steel roller, the tested tube was crushed to about 4 mm. The strain applied to the surfaces of the

tested tubes at this time was 0.17%. As a result of the test, both tubes (a) and (b) did not exhibited any abnormality in the tested tube even after over 1 million cycles.

Example 2

Annealed foils having surface roughnesses Rz of 1.0 μm and 0.5 μm, made of SUS316L (16%Cr-12%Ni-2%Mo), and having thicknesses of 30 μm were slit to 60 mm widths. These were wrapped in spirals around the above 30 mmϕ copper alloy electrode rods. At this time as well, the foil with the surface roughness Rz of 1.0 μm and the foil with the surface roughness Rz of 0.5 μm were adjusted so that the overlap between sections of the foil became 100 μm. Further, it is possible to rotate the electrode rod and make it slide to the left and right and to roll over the overlap part by another copper alloy or other rolling electrode roller and pass current with the electrode rod for mash seam welding. The same procedure was followed as in Example 1 to investigate the hardnesses of the vicinities of the joint zones of the two tubes ((c) tube having a surface roughness Rz of 1.0 μm and (d) tube having a surface roughness Rz of 0.5 μm). As a result, in both tubes, the matrix part had a hardness Hv of around 200 and the joint zone a hardness of around 245. Further, the inventors investigated the metal structures and confirmed that there were no melted and solidified phases in both tubes. The two tubes (see FIG. 1(D)) were cut to lengths of 50 mm, the inside and outside parts near the joint zones were polished, and the same procedure was used as in Example 1 for a fatigue test.

Note that the strain applied to the surface of the tested tubes in the test was 0.13%. The result was that the two tubes (c) and (d) withstood the fatigue test for 1 million cycles or more.

Example 3

Completely annealed foils having surface roughnesses

Rz of 0.3 μm and 0.8 μm, made of SUS304 (18%Cr-8%Ni), and having thicknesses of 50 μm were used by the same method as in Example 1 to prepare two types of foil tubes. Note that the stainless steel foils were annealed in an Ar-H_2 atmosphere. The nitrogen concentrations of the surfaces were 1.2%. In both cases ((e) tube having surface roughness Rz of 0.3 μm and (f) tube having surface roughness Rz of 0.8 μm), the joint zones had thicknesses of 75 μm. The inside and outside surfaces were polished to 60 μm. In this case, with both tubes, the hardness of the matrix part was about, in terms of Hv, 178, while that of the joint zone was, in Hv, around 220. The same procedure was followed as in Example 1 for a fatigue test. The result was that both tubes (e) and (f) withstood the fatigue test for 1 million cycles or more.

Example 4

A completely annealed foil having a surface roughness Rz of 0.34 μm, made of SUS304 (18%Cr-8%Ni), and having a thickness of 50 μm was used by the same method as in Example 1 to prepare a foil tube. Note that this stainless steel foil was annealed in ammonia decomposition gas and the nitrogen concentration at the surface was 4.4%. The thickness of the joint zone was 77 μm. This was reduced by polishing the inside and outside surfaces to 60 μm. The hardness of the matrix part in this case was, in terms of Hv, around 190, while the hardness of the joint zone was, in terms of Hv, around 230. The same procedure was followed as in Example 1 for a fatigue test. As a result, the tube developed fine cracks in the surface of the matrix at the time of 500,000 cycles, so the fatigue test was suspended, but depending on the application, the tube had durability up to 500,000 cycles. Depending on the application, this was sufficient for use.

Example 5

A hard material having a surface roughness Rz of 0.5 μm, made of SUS304 (18%Cr-8%Ni), and having a thickness of 50 μm was used by the same method as in Example 1 to prepare a foil tube. The joint zone had a thickness of 90 μm. This was polished at the inside and outside surfaces to 60 μm. The hardness of the matrix part in this case was, in terms of Hv, around 410, the hardness of the joint zone was, in terms of Hv, around 230, and the hardness difference of the joint zone and matrix part was 43% of the hardness of the matrix part. The same procedure was followed as in Example 1 for a fatigue test. As a result, this tube cracked and broke at the interface between the joint zone and matrix at 500,000 cycles. In this case as well, depending on the application, the tube had a durability of up to 500,000 cycles. Depending on the application, this was sufficient for use.

Example 6

A rolled foil having a surface roughness Rz of 0.7 μm, made of SUS420J1 (13%Cr-0.18%C), and having a thickness of 20 μm was used by the same method as in Example 1 to prepare a foil tube. The joint zone had a thickness of 32 μm. The inside and outside surfaces were polished to 23 μm. The hardness of the matrix part in this case was, in terms of Hv, around 340, while the hardness of the joint zone was, in terms of Hv, around 315. The same procedure was followed as in Example 1 for a fatigue test. The result was that this tube withstood the fatigue test for 2 million cycles or more.

Example 7

A rolled foil having a surface roughness Rz of 0.9 μm, made of SUS630 (17%Cr-4%Ni-4%Cu-0.2%Nb-0.1%Ta), and having a thickness of 20 μm was worked by the same method as in Example 1 to prepare a foil tube. The joint zone had a thickness of 35 μm. This was polished at the inside

and outside surfaces to 26 μm. After this, a vacuum heat treatment furnace was used to heat this to 1040°C. This was soaked in a cooling process at 480°C for 1 hour to precipitation harden it. The hardnesses of the matrix part and weld zone were substantially the same or, in terms of Hv, around 380. The same procedure was followed as in Example 1 for a fatigue test. The result was that this tube withstood the fatigue test for 2 million cycles or more.

Example 8

A rolled foil having a surface roughness Rz of 0.85 μm, made of YUS170 (Nippon Steel Corporation's specification: 24%Cr-12%Ni-0.7%Mo-0.35%N), and having a thickness of 25 μm thickness was worked by the same method as in Example 1 to prepare a foil tube. The joint zone had a thickness of 30 μm. This was polished at the inside and outside surfaces to 22 μm. The hardness of the matrix part in this case was, in terms of Hv, around 290, while that of the joint zone was, in Hv, around 220. The same procedure was followed as in Example 1 for a fatigue test. The result was that this tube withstood the fatigue test for 1 million cycles or more.

Comparative Example 1

The same procedure was followed as in Examples 1 to 8 except that the stainless steel foils were joined by laser welding instead of the electrical resistance welding (mash seam welding) in Examples 1 to 8 to prepare foil tubes of the stainless steel foil materials for use in a fatigue test. In each case, the boundaries of the joint zones and matrixes cracked and broke at 100,000 to 300,000 cycles.

Comparative Example 2

The same procedure was followed as in Examples 1 to 8 except that the stainless steel foils were joined by plasma welding instead of the electrical resistance welding (mash seam welding) in Examples 1 to 8 to prepare

foil tubes of the stainless steel foil materials for use in a fatigue test. In each case, the boundaries of the joint zones and matrixes cracked and broke at 100,000 to 300,000 cycles.

Example 9

A 0.9 μm surface roughness Rz, SUS304, 60 μm thick fully annealed foil (nitrogen concentration of surface of 1.2%) annealed in an Ar-H_2 atmosphere was used by the same method as in Example 1 to fabricate seven 24 to 30 mmϕ x 250 mmL tubes by mash seam welding. After this, six of these were worked by inserting quenched S45C metal cores into the tubes, cold working them by sedging, split roller rolling, drawing, spinning, or a combination of the same to reduce the thicknesses, smooth the weld zones, even out the shapes and surface roughnesses of the weld zones, and simultaneously work harden the materials to thereby obtain around 30 μm thick foil tubes. These foil tubes were measured before and after cold working (that is, unworked and worked) for dimensions, materials, fatigue life, etc. The results are summarized in Table 1.

[Table 1]

Working method / Dimensions, materials, etc.	(1) as welded	(2) sedging	(3) 3-split-roller rolling	(4) drawing	(5) spinning	(6); (2)+(3)	(7); (5)+(4)
Tube thickness (μm)	60	28	32	34	30	29	30
Hardness (Hv)	220	467	423	396	448	454	445
Weld zone surface roughness Ra (μm)	0.62	0.33	0.18	0.12	0.29	0.19	0.12
Weld zone surface roughness Rz (μm)	5.22	1.96	1.36	0.99	1.91	1.58	0.91
Fatigue life (hr)	456	818	732	701	763	774	753

In Table 1, the tube thickness is the thickness of the non-joint zone (matrix part), the hardness is the Vicker's hardness of the matrix part, the surface roughness Ra of the weld zone is the value measured by (JIS B0601 2001 arithmetic average roughness), and the surface roughness Rz of the weld zone is the value measured by JIS B0601-2001 (maximum height roughness) of the metal foil.

Further, the fatigue life of Table 1, like in Example 1, is the value found by inserting a hard sponge cylinder into each foil tube and rotating this while pressing against the surface of a 120 mmϕ x 80 mmL steel roller so as to investigate the fatigue life. The rotational speed of the tested tube at this time is 360 rpm. In the state pressed most against the steel roller, the tested tube is collapsed to about 4 mm. The strain applied to the surface of the tested tube at this time was successively (1) 0.34, (2) 0.16, (3) 0.18, (4) 0.19,

(5) 0.17, (6) 0.16, and (7) 0.17%. The test was conducted until cracks or other abnormalities could be confirmed in the foil tube. The fatigue time (hr) during this time was designated the fatigue life.

Note that, the cold workings of (2) to (7) of Table 1 were performed starting from welded tubes with the following inside diameters before cold working by the respective cold working methods.

That is, (2) sedging; 26 mmϕ welded tube, (3) three-piece roller rolling; 24 mmϕ welded tube, (4) drawing; 30 mmϕ welded tube, (5) spinning; 24 mmϕ welded tube, (6): (2)+(3); 24 mmϕ welded tube, (7): (5)+(4); 26 mmϕ welded tube.

Example 10

Completely annealed foils annealed in an Ar-H_2 atmosphere, having surface roughnesses Rz of 1.2 μm, made of SUS301, SUS201, SUS316N, and YUS170 (24%Cr-12%Ni-0.3%N), and having thicknesses of 25 μm (nitrogen concentrations of surfaces of 1.7 to 2.4%) were used by the same method as in Example 1 to prepare 30 mmϕ x 250 mmL tubes by mash seam welding. After this, these tubes were worked in the same way as in Example 9 by sedging+split roller rolling (the (6): (2)+(3) cold working) to obtain around 25 μm thick foil tubes. The dimensions, materials, fatigue life, etc. of the foil tubes before and after cold working are shown in Table 2.

[Table 2]

Material etc. \ Material	SUS301		SUS201		SUS316N		YUS170	
	(8) as welded	(9) after working	(10) as welded	(11) after working	(12) as welded	(13) after working	(14) as welded	(15) after working
Tube thickness (μm)	50	27	50	25	50	24	50	25
Hardness (Hv)	251	608	235	512	198	497	211	511
Weld zone surface roughness Ra (μm)	0.42	0.29	0.51	0.18	0.55	0.17	0.45	0.20
Weld zone surface roughness Rz (μm)	3.45	1.96	2.73	1.32	3.72	1.45	2.57	1.42
Fatigue life (hr)	328	857	228	723	208	785	325	817

Note that the tube thickness (μm), hardness (Hv), weld zone surface roughness Ra (μm), weld zone surface roughness Rz (μm), and fatigue life (hr) of Table 2 are as explained in Table 1.

Note that the strains given to the surface of the tested tubes in the fatigue life were, in order (8) 0.28, (9) 0.15, (10) 0.28, (11) 0.14, (12) 0.28, (13) 0.14, (14) 0.28, and (15) 0.14%.

Example 11

25 μm thick SUS316 foil was seam welded by the same method as in Example 1 method to obtain a 30 mmϕ x 250 mmL foil tube. This was plated with hard Cr to a target thickness of 2 μm. The foil tube had a rod-shaped Cr electrode inserted inside it and was plated with Cr over its inside and outside surface. Further, another SUS316 foil tube welded in the same way was electrolessly plated by Ni-8%P, Co, Pd respectively to a target thickness of 2 μm. These tubes were cut at their ends, the cross-

sections were buried and polished, and the thicknesses of the plating films (layers) were investigated. Separate from these, for measurement of the hardness of the plating layer, iron sheets were plated with the same materials to thicknesses of about 30 μm, buried in resin, polished, then measured for hardness. As a comparison with the plated foil tubes, an unplated foil tube was attached as a fixing roll of a printer, half a pinch's worth of iron powder was sprinkled on the inside surface of the tube, then the tube was rotated for 10 minutes. After this, the tube was detached and cut open to investigate the state of formation of flaws at the inside surface. The results are summarized in Table 3.

[Table 3]

	Plating layer thickness	Plating layer hardness Hv	State of formation of flaws
Unplated foil tube	--	--	Tens of stripe-shaped flaws
Ni-8%P plated foil tube	2 μm	562	No flaws
Co plated foil tube	3 μm	432	No flaws
Pd plated foil tube	2 μm	481	No flaws

As shown in Table 3, the hardnesses of the plating layers were all, in terms of Hv, 400 or more. These foil tubes did not become flawed even in an adverse environment with iron powder sprinkled on the inside surfaces of the fixing rolls. As opposed to this, the unplated foil tube exhibited several stripe-shaped flaws.

Example 12

30 μm thick SUS316 foils were electrolessly plated on their two surfaces with Ni-2%P, Ni-8%P, and Ni-12%P to thicknesses of about 2 μm. Further, separate from these, the vicinities of the foils forming the weld zones, that is, the 2 to 3 mm distances from the cut edges, at the

two sides were electroplated with Al and Ag to thicknesses of about 2 μm. These foils were welded by mash seam welding to form 30 mmϕ x 250 mmL tubes. The weld zones were cut out, buried, and polished, then the cross-sections and metal structures of the weld zones were examined. As a result, the thicknesses of the matrix parts, including the plating layers, were 34 μm, while the thicknesses of the weld zones where the two sides of the foil were superposed were 35 to 37 μm or substantially the same thicknesses as the matrix parts. Further, the weld zones were tightly bent, buried in resin, and examined for the metal structure at the bent parts. As a comparative material, unplated SUS316 foil of a thickness of 40 μm was mash seam welded in the same way as the above SUS 316 foil, the weld zone was cut out, and that part was tightly bent. Further, this part was buried in resin, polished, and examined for metal structure. As a result, the weld zone of the unplated foil opened slightly at the part where the joint line reached the foil surface due to the tight bending, but the tightly bent part of the weld zone of the plated foil did not open at all.

Example 13

40 μm thick SUS304 and SUS420J2 foils were welded by mash seam welding to form 30mmϕ x 250 mmL tubes. After welding, the SUS304 tube was vacuum heat treated at 1030°C for 3 minutes, while the SUS420J2 tube was vacuum heat treated at 880°C x 10 minutes. The vicinities of the weld zones of the tubes after heat treatment were cut out, were tight bent about the weld zones, and were buried, polished, etched, and examined for the structures of the weld zones. As a result, the weld zones did not open at all and could withstand tight bending.

Example 14

The SUS304 and SUS420J2 foil tubes prepared in Example 13 were electrolessly plated at the inside and

outside surfaces by Ni-8%P. These tubes were tested for flaws by iron powder similar to Example 11, but no stripe-shaped flaws were caused. Further, these tubes were used for the above fatigue tests. With both, no destruction of the weld zone could be found even after the elapse of 7.5 million cycles.

Example 15

A 40 μm thick SUS316 foil was used to form a 30 mmϕ x 250 mmL tube by seam welding. At that time, the welding power source used was a pulse power source, the ratio of the conduction time and non-conduction time was changed in various ways, the metal structure of the weld zone was examined, and the state of formation of the nuggets was examined. The results are shown in Table 4.

[Table 4]

Conduction time/non-conduction time	1/20	1/15	1/14	1/12	1/10	1/8	1/7	1/6	1/5
Ratio of nugget length (%)	36	52	63	100	100	100	54	18	0
Remarks	Comp. ex.	Inv. ex.	Inv. ex.	Inv. ex.	Inv. ex.	Inv. ex.	Inv. ex.	Comp. ex.	Comp. ex.

As shown in Table 4, with the conduction time/non-conduction time set to 1/15 to 1/7, the nugget length became 50% or more along the weld line. It was learned that good welding was performed.

INDUSTRIAL APPLICABILITY

In the metal foil tube of the present invention, compared with the prior art of joining sections of a metal sheet by press working, laser welding, plasma welding, etc. to form a tube blank and working this tube blank by for example ironing, spinning, drawing, bulging, or other thinning technology to form a thin tube, by rolling the metal sheet and, in accordance with need, annealing or heat treating it to reduce its thickness, it is possible to mass produce metal foil or tubes of the

desired thickness, so it is possible to remarkably lower the production costs compared with the case of thinning individual tube blanks.

Further, in the prior art, when thinning a tube blank formed into a tubular shape by press working, laser welding, plasma welding, etc., the surface of the tube blank is subjected to strong mechanical stress, so an orange peel surface (drop in surface smoothness) is inevitable, but in the present invention, it is possible to obtain metal foil excellent in surface smoothness by rolling, possible to use this metal foil to form a finished metal foil tube, and possible to use the metal foil as it is without thinning, so the superior surface smoothness can be held.

Further, in the present invention, since the metal foil is welded by electrical resistance welding to form a tube, control of the joining process is simple and it is possible to produce an extremely thin metal foil tube well. Therefore, compared with the conventional practice of laser welding, plasma welding, etc. to form a tube blank and thin this to form a thin tube, it is possible to reduce the difference in hardness between the joint zone and non-joint zone and possible to suppress the drop in durability due to the metal fatigue at the boundary between the joint zone and non-joint zone. Further, regarding the problem of weld separation at the weld zone as well, with a thin tube obtained by forming a tube blank by conventional laser welding, plasma welding, etc. and thinning it, at the time of thinning, the weld zone is subjected to large working of about 90%, so weld separation easily occurs due to later use, but in the present invention, no large working is applied after welding, so the problem of weld separation of the weld zone etc. does not easily occur.

Further, the present invention is advantageous in the point that it is possible to select any material as the metal foil in accordance with the application. That

is, in the present invention, it is possible to use an existing material, from hard materials to soft materials, and possible to suitably select a material satisfying the high elasticity, high rigidity, light weight, thinness, high heat conductivity, and other performance requirements in accordance with the application.

Further, in the present invention, by hard plating the inside and outside surfaces of the tube, even if foreign matter is carried in along with the paper, it is possible to suppress flaws in the roller and possible to suppress the detrimental effect on the results of printing. Further, by hard plating, at the time of seam welding, even if nuggets formed by melting and solidification are not continuously formed, the plating layer will melt and a complete metal bond will be obtained along the weld line. Therefore, this part can give a sufficient joint strength in the crimped state and the product yield and quality can be improved.

The method of production of the metal foil tube of the present invention can shape even a metal foil sheet having a thickness of 10 to 100 μm to form an overlap part, then weld the facing sides and finish this weld zone part smooth, so can reliably finish even extremely thin metal foil into a tube shape.

This shaping does not round the metal foil all at once. It positions the foil, then wraps it around a core rod having an electrode, forms an overlap part, then welds it, so extremely precision shaping is possible and welding is also easy. This overlap part is also formed while adjusting the overlap, so greater precision shaping becomes possible. If the overlap (x) satisfies $x \leq 40+5t$ (unit μm) with respect to the thickness (t), it is possible to weld together the two ends even with an extremely thin metal foil.

The welding is electrical resistance welding, so control of the welding is simple and extremely thin metal

foil can be produced well. Further, by providing the core rod serving as the inside die with a stationary electrode member, providing a movable electrode member facing this stationary electrode member, and running current across the two over the metal foil, it is possible to join the two ends of the metal foil with a good precision.

The production apparatus of the present invention is provided with a shaping device for holding a metal foil sheet to be able to approach or move away from the circumference of a core rod with a circular cross-section perpendicular to the axis, so even with an extremely thin metal foil with a thickness of 10 to 100 μm, it is possible to shape the foil to form the overlap part, then weld the facing sides and reliably finish the foil into a tube shape.

The tube is shaped by wrapping and positioning the foil against the core rod by a holding plate for bending the metal foil sheet into a U-shape and for a first pressing member and second pressing member pressing the sides against the circumference of the core rod and overlapping the facing side ends, so it is possible to shape the tube extremely precisely and later weld it easily as well.

The overlap of the overlap part is adjusted by using offsetting devices (cams, rollers, etc.) provided at the inside or outside of the core rod to press against the non-contact parts of the metal foil sheet or by a pressing member for pressing the metal foil sheet toward a recess formed in the core rod, so more precise shaping becomes possible.

The welding is performed by providing the core rod serving as the internal die with a stationary electrode member, providing a movable electrode member facing this stationary electrode member, and running current across the two over the metal foil, so it is possible to connect the two ends of the metal foil with a good precision. Further, if making the movable electrode member an

electrode ring, smooth, good precision welding becomes possible. If making the hardness of the electrode member and the hardness of the metal foil sheet substantially the same, good precision welding over a long period becomes possible.

After shaping the metal foil tube, if ejecting a fluid from the core rod in the radial direction or using a split core rod, the metal foil tube can be easily separated from the core rod and even an extremely thin metal foil tube can be easily detached.